Motivation and Value: Effects on Attentional Control and Learning

by

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Dedication

To my beloved father,

Lin Minxian

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This dissertation is about motivation and value. I often sit back and ask myself: What motivates me? The quest of learning, and the love and support from all of you.

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Abstract

My dissertation presents two lines of research that examine motivation-cognition interactions. The first focuses on the effects of gain and loss incentive on attentional performance in young and older adults, examines which aspects of attention/cognitive control may be most sensitive to incentive manipulations, and takes steps towards elucidating the cognitive-motivational states and traits that may mediate those effects. When monetary incentives were offered throughout the experiments, they tended to have no effect or a small beneficial effect on the focused attention of young adults, and decreased young adults' subjective reports of mind-wandering. In contrast, older adults had worse performance and more mind-wandering under incentive, especially loss incentive. Monetary incentives offered in alternating runs reduced the overall performance of both young and older adults compared to groups for which incentive was not offered at all, whereas within the alternating-run groups, performance was worse on the runs without incentive. Additional results from self-report measures suggest that for young adults, decreased performance under incentive may be the result of distraction. In contrast, older adults were more intrinsically motivated, and decreases in motivation under external incentive may underlie their reduced performance. In short, these results demonstrate that incentives may sometimes paradoxically reduce, rather than increase, performance, and that the direction and underlying mechanisms of incentive effects are influenced by factors including age (young vs old) and incentive structure (between- or within-subject manipulation).

The second line of research investigates how outcome probability and valence may influence learning as well as subsequent explicit memory. Participants first learned to associate scenes with wins or losses that occurred at high or low probability, with probability thought to influence the "motivational salience" of the scene. The task objective was to maximize the reward (points or points and money) earned in each trial, and the optimal choices are the high probability win scene and the low probability loss scene. Contrary to the common assumption that win and loss outcome associations are learned equally, win associations were learned better than loss associations, suggesting an advantage for learning outcomes with a positive valence. A subsequent recognition task assessed explicit knowledge of the learned value associations. Regardless of learning level or incentive conditions, memory for the association between a scene and its valence and motivational salience was superior for scenes that had previously been the optimal choice (high probability win and low probability loss). However. accurate recognition was significantly better for optimal win scenes than optimal loss scenes. These findings indicate that learning to select the optimal choice is dissociable from explicit knowledge about the outcome contingencies, especially for loss and low probability outcomes. Moreover, motivational salience is represented differentially in explicit memory for win and loss outcomes.

Together, this research examines several common assumptions about incentives and motivation in attention, learning, and memory in previous research studies, and demonstrates that the effects are more complex than currently realized. The discussion considers the implications for understanding the mechanisms underlying incentive effects on different types of cognition, as well as the effects of incentive in everyday life.

Chapter I. Introduction

What is motivation?

The Oxford Dictionary defines motivation as "a reason or reasons for acting or behaving in a particular way ('motivation,' 2018)." Motivation is a common word in everyday life. In research contexts, however, motivation is not a unified concept and can have different meanings. The research on motivation in psychology and neuroscience has a long history. However, different areas in these disciplines have distinct operationalized definitions and use a wide variety of research paradigms to study motivation (Braver et al., 2014). These different concepts have led to a diverse body of theories in motivation on human and animal behaviors.

The major historical divergence in the study of motivation is among behavioral neuroscience, social/personality/educational psychology, and cognitive psychology/cognitive neuroscience. In behavioral neuroscience, motivation is an evolving concept. Historically, the study of motivation focused on homeostasis and drives (Berridge, 2004). In the context of behavioral neuroscience, homeostasis in this context refers to an internal system using a setpoint to maintain a stable state. Any deviation in the current physiological state from this internal setpoint results in an error and activates the homeostasis system to perform appropriate responses (Hull, 1943). While many theories developed based on homeostasis and drive, behavioral neuroscience has moved from simple homeostatic drives to study the complex of emotional and cognitive processes typically thought of as "real motivation" that leads to flexible instrumental behaviors (Teitelbaum, 1977). Concepts of incentive value and incentive learning developed in to different theories about incentive motivation (Berridge, 2004). Incentive value refers to the probability of an outcome associated with a particular behavior. Experimental studies in this tradition investigate how value is learned; for example, Paradigms of Pavlovian conditioning and instrumental learning are often used to study the behavioral and neural responses of an agent (e.g. a rat) to a stimulus or an action with previously learned outcomes. A brief review of different systems for value learning is provided in Chapter IV.

Social, personality, educational psychology theories of motivation often focus on how motivation functions and interacts with different levels of personal, social and organizational contexts (Ryan, 2012). Braver and colleagues (2014) argue that goals are the fundamental conceptualization of motivation in this field. Goals can be defined as the representation of specific aims that guides behavior (Elliot & Fryer, 2008). Here, goals can vary across different domains, such as education, social relations, sport, and work. Research studies on these goal domains, contexts and functions has generated rich and diverse frameworks in this field. For example, Achievement Goal Theory is concerned with learning and performance, focusing on the interplay between mastery goals and performance goals with regard to outcome (see review by Murayama et al., 2012). This theory originated from studies on children's learning behaviors (Elliot, 2005). There are also other theories that were developed in the field and applied to various domains. One example is Self-Determination Theory (SDT, Deci & Ryan, 2012), which developed from studies comparing intrinsic and extrinsic motivations. This theory centers on the extent to which behaviors are autonomous (i.e. behaviors that are initiated for oneself) vs controlled (behaviors that are pressured and influenced by external factors). The STD has been applied in domains such as health behaviors, organizational studies, and sport and exercise (Ryan, 2012). In the fields of social, personality, and educational psychology, self-report methodology is one prominent way of studying motivation (Fulmer & Frijters, 2009). In recent years, experimental methods have also developed to measure implicit or unconscious motivation, such as using priming and implicit rating task (Thrash et al., 2012)

Cognitive psychologists and neuroscientists study the process and mechanism of motivation and how it affects behaviors and cognition (Kringelbach & Berridge, 2016). In these fields, experimental manipulations often use extrinsic incentives (i.e. money). A very common paradigm is the monetary incentive delay (MID) task (Knutson et al., 2000; Lutz & Widmer, 2014), in which a cue indicates the amount of money that can be earned/lost for successful/failure performance before a subject performs a trial. The performance difference between incentivized and non-incentivized conditions or trials is viewed as an index of the effect of motivation. With the development of neuroimaging techniques, cognitive neuroscientists have started to examine the neural correlates of motivation and how it may influence different cognitive processes.

This brief review demonstrates differences in how motivation is conceptualized and operationally defined in different fields or even within one field. The division in different subfields has advanced our understanding of distinct aspects of motivation. It is important to point out that these distinctions also reflect the complex and rich nature of motivational states and behaviors. However, while each subfield has developed and progressed within their own area, differences in definition of motivation and in research methodologies pose challenges for interdisciplinary communications and collaborations. Braver and colleagues (2014) summarized a number of limitations in different subfields of motivation research. For example, behavioral neuroscience primarily studies the effect of motivation on a limited behavioral repertoire and rarely studies higher cognitive processing. On the other hand, cognitive psychology and cognitive neuroscience are rigorous in experimental control but hardly considers complex individual factors that may affect motivation.

The current dissertation examines the interaction between cognition and motivation. Experiments presented in this dissertation aim to address some of the abovementioned shortcomings in hopes of developing a more collaborative approach to the study of motivation. In recent decades, researchers have made efforts to facilitate collaborative investigations across areas so that areas of research on motivation will no longer be studied in isolation. Human research has started using paradigms from animal learning and behavioral neuroscience to examine effects of learned value information processing. Social and educational psychologists use neural imaging tools to study how the effects of motivation in social and educational contexts may influence cognition and the neural mechanisms behind them. Meanwhile, cognitive psychologists and neuroscientists have also extended their research scope to consider the influence of individual differences and social contexts on motivation and cognitive processes.

Since the definition of a concept determines the scope of research, I will define motivation based on consistency across fields (Braver, 2014). By motivation, I refer to the processes by which goal-directed behaviors are maintained and sustained, maximizing positive outcomes and minimizing negative outcomes (Young, 1959; Elliot & Covington, 2001). Importantly, there are two levels of motivation: motivational orientation and motivational state. The former is a more trait-like level of motivation that is relatively stable. The latter is a more state-like level of motivation that constantly changes as a result of dynamic interactions with the environment. When discussing motivation in a life-span and aging context, I refer to the trait-like level of motivation. For experimental manipulations, the state-like is often operationally defined in specific experiments.

Dissertation Overview

In this dissertation, I present two lines of research. Chapters II and III focus on the effects of gain and loss incentive on young and older adults. Chapter IV examines the effects of outcome valence and motivational salience on learning and source recognition. Although the convergence of the two lines of research may not be immediate and apparent, they are both empirical investigation of motivation-cognition interactions, addressing some of the important issues in the field. These two lines of research share two relevant aspects: 1) First, they research use monetary incentives as manipulation, allowing us to test the effects of incentive on performance in different cognitive domains; second, they manipulate valence, allowing us to gain more insights into the effects of gain and loss processing.

In the rest of this chapter, I provide a brief review of topics in motivation research that are relevant to my dissertation. Within each empirical chapter, an embedded introduction further motivates each set of the experiment. Table 1 provides an outline of topics addressed in each chapter. Chapters II and Chapter III investigate the effects of monetary incentives on young and older adults. To address the ecological-validity issues of using trial-by-trial incentive manipulation, both chapters use a task-wise incentive manipulation, mirroring real-life situations in which incentives are often seamless and without a clear cue. While Chapter II uses a between-subject manipulation, Chapter III uses a mixed design to explore temporally specific and general context effects. Chapter IV examines the effects of outcome valence and outcome probability on learning. The learned association is also assessed through a source recognition task. Chapter V presents a brief summary of the findings, discusses real-world applications, and considers future directions for research and for potentially bridging these two research lines.

Table I-1 Outline of studies and topics addressed in each chapter.

Aim	Chapter	Topics Addressed
	Chapter I: Introduction	
Aim1: Effects of Gain and Loss Incentive on Young and Older Adults		
	Chapter II	Age and Motivation
	Chapter III	Age and Motivation, Extrinsic and Intrinsic Motivation
Aim 2: Effect of Outcome Valence and Motivational Salience on Learning Recognition		
	Chapter IV	Value and Reward
	Chapter V: Summary	

Motivational Changes in Aging

A large body of research has documented the neurocognitive changes in old age (Park & Reuter-Lorenz, 2009). However, these age-related changes in neural and cognitive functions may not always explain age-related performance differences (Braver, 2014). In recent years, how motivation modulates cognitive processing in old age has gained considerable attention in research. To investigate motivation-cognition interactions in old age, it is also important to understand age differences in motivation and their potential impact on cognitive processes.

Two accounts have been proposed to explain the change of motivational priorities in old age. One perspective argues that the motivational shift in old age is a self-regulatory strategy to adapt to environmental and experiential changes that occur with aging. A prominent theory in this account is the socioemotional selectivity theory (SST; Carstensen, 1992; 1999). According to SST, when one's future lifetime is perceived to be limited, emotionally meaningful goals are prioritized over future-oriented goals, such as growth and acquiring new experience. The SST argues that this motivational shift in aging is adaptive. While older adults change goal priority as a function of limited future time, their preference of processing positive information over negative information helps them not only maintain positive affect, but also shapes and selects the environment they interact with. The preference for positive over negative information in old age is manifested in cognitive processing. The pattern that older adults, compared to younger adults, remember and pay attention to positive over negative information is referred as the "positivity effect" (Mather & Carstensen, 2005; Reed et al., 2014).

An alternative perspective focuses on age-related declines and proposes that the declines in physical and neurocognitive functions in old age lead to shifting motivational goals. For example, Cacioppo and colleagues (2011) have proposed an aging-brain model that suggested the positivity effect is an effect of reduced responsiveness to negative stimuli as a consequence of age-related amygdala degeneration. The selection, optimization, and compensation (SOC; Baltes, 1997; Freund & Baltes, 2000) proposed that the balance of maximizing gain (growth) and minimizing loss across lifespan is the key to successful development. With decreasing resources in old age, individuals shift away from activities associated with growth and emphasized maintenance and loss prevention.

Chapter II and Chapter III in my dissertation use an attentional task in healthy young and older adults to examine how monetary incentives affect their attentional performance. Relevant to motivational changes in aging, the monetary incentive in the two studies is manipulated in gain, loss, and control conditions. These two chapters test predictions regarding potential differences in how young and older adults respond to positive vs. negative incentive information. Findings from these studies contribute to our understanding on what components of performance are affected and offer insights on why they are affected.

Extrinsic and Intrinsic Motivation

Research on motivation in cognitive psychology and cognitive neuroscience has mostly used incentives by providing participants performance-based monetary rewards. Although it is commonly assumed that incentives, in this case monetary incentives, have beneficial effects on performance, in reality findings are mixed. For example, Camerer and Hogarth (1999) reviewed 74 studies with incentive manipulations that vary levels of reward. They found that monetary incentives did not always improve performance and sometimes even decrease performance. They argued that the effects of the incentive depend on several factors, including task difficulty, match with subject's skill, and the magnitude of the reward. In the studies researchers reviewed, the most common result was null effect of monetary incentive (or not measurable). Another study conducted by Bonner and colleagues (2000) found that about half of the experiments included in their analysis showed an enhancement effect of monetary incentives; the other half of showed null effects or even detrimental effects. They noted that the complexity of the task was negatively correlated with the enhancement effects of monetary incentives.

One of the major theories developed from behavioral works is self-determination theory (SDT; Deci & Ryan 1985; 2012). This theory draws a distinction between intrinsic and extrinsic motivation. Intrinsically motivated activities are inherently satisfying whereas extrinsic motivated activities are driven by external rewards or incentives (e.g. food or money). Since extrinsic rewards are provided by external sources, these rewards may undermine one's self-determination and intrinsic motivation. This theory is often used to explain findings on the negative effects of monetary incentives, termed the “undermining effect” (Deci et al., 1999, Hidi, 2016).

As mentioned earlier, most cognitive psychology and cognitive neuroscience studies exclusively have used extrinsic incentives, paying little attention to intrinsic motivation. My dissertation addresses this issue by including self-reported measures of intrinsic motivation in Chapter III. In addition to use performance index (difference between incentivized performance and non-incentivized performance), we also included self-reported measures to assess participants’ subjective motivation. Similar to most of the cognitive psychology and cognitive neuroscience studies, experiments in Chapter II and III use monetary incentives to manipulate extrinsic motivation. Most previous studies in this domain use trial-by-trail incentive cues to indicate prospect of the reward. However, in real-life situation, incentives are often more seamless and applied to the entire situation. We therefore sought to emulate this latter situation by using a task-wise, between-subjects manipulation of incentive in Chapter II. Chapter III combines this between-subjects manipulation with a within-subjects (alternating runs) manipulation to demonstrate that these two different structures for manipulating incentive can have very different – and indeed opposite – effects.

Reward and Value

Motivation is closely related to reward because it is a process oriented toward a prospect of a reward (Botvinck & Braver, 2015). In many research contexts, reward and value are used interchangeably. In my dissertation, value refers to the amount of reward one expects to obtain from an action. In Chapter IV, value learning refers to the learning process of forming an action-outcome representation in order to obtain and make prediction about a reward. This type of learning has been referred to by various labels in different areas of psychology and neuroscience, such as value-based decision making, reward learning, and reinforcement learning. This area of research has strong connections with behavioral neuroscience research in animal learning. The essence of value learning is to associate an otherwise neutral stimulus with a value, allowing an agent to optimize behavior by learning to predict the outcomes of actions. Learning to associate value with new stimuli is essential to functioning flexibly and adaptively in complex environment.

Research on value learning has been rapidly growing in the past decade. As mentioned in earlier sections, the study of motivation in behavioral neuroscience often has focused on a limited set of behaviors and is constrained in the degree to which it can investigate how motivation influences higher cognitive processing. Research on reward, value, and value learning has extended our insight into how learned value influences cognitive processes. There are two main research approaches in this area. One focuses on investigating the neural mechanisms of value signals in the brain. This approach often uses neuroimaging tools such as fmri to study value learning. Findings from this approach have been very fruitful (see a review by O'Doherty, Cockburn, & Pauli, 2017). The other is a two-pronged approach: Stimuli from a prior value learning or value decision-making task are incorporated in a subsequent follow-up or secondary task to examine the consequences of prior learning. These studies typically both assume that participants have acquired value associations during the initial learning task and make inferences about what was learned based on the performance of the secondary task. Researchers have used the second approach to study how learned value influenced different cognitive processes, such as perceptual processing (O'Brien & Raymond, 2012), attention (Anderson, Laurent, & Yantis, 2011; Della Libera, & Chelazzi, 2009; Raymond and O'Brien, 2009), motor control (Painter, Kritikos, & Raymond, 2013), working memory (Thomas, FitzGibbon, & Raymond, 2016) and associative memory (Aberg, Müller, & Schwartz, 2017). Together, these investigations provide new insights into the neural mechanism of how value is represented in the brain and how value may influence high cognitive processing.

Chapter IV uses a similar two-pronged approach. However, the secondary task is specifically designed to assess participants' explicit knowledge of the learned associations.

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Chapter II. The Effect of Gain vs. Loss Incentive on Different Types of Attention in Young and Older Adults

Abstract

It seems intuitive that receiving money for good performance or losing money for poor performance would increase attention and performance - but is this true across age groups and different aspects of attention? Previous studies have suggested that older adults are insensitive to loss, but this pattern is discrepant with workplace studies and may be the outcome of trial and incentive structures that facilitate stimulus-driven attention. We tested younger and older adults in a task that assesses three aspects of attentional control (focusing attention, sustaining attention, resisting distraction) under no-incentive, gain-incentive, or loss-incentive conditions. Incentive tended to improve the focused attention of young adults and decreased their subjective reports of mind-wandering. In contrast, older adults had worse performance and more mind-wandering under incentive, especially the loss condition. These deleterious effects were statistically eliminated by controlling for mind-wandering, suggesting that loss incentives may paradoxically decrease motivation and focus in older adults.

Introduction

We have tried to make this paper as interesting as possible, but at some point, your attention will wander. Would your focus improve if by correctly answering questions about the paper's contents, you could earn up to $20? What if we gave you $20 now, but for every question you got wrong, we took some money back?

Incentives are often used to improve attention and performance in laboratory experiments and everyday life, presumably by increasing motivation. Motivation-cognition interactions have become a topic of intense scientific interest, with the publication rate on this topic nearly doubling over the past decade. Reviewing this literature, Botvinick and Braver (2015) remarked, "the most fundamental set of phenomena linking control with motivation involves effects of incentives… The most common observation….introduction or enlargement of performance-contingent rewards or punishments results in improvements in task performance, specifically attributable to enhanced executive control." (pg. 87) This observation seems intuitive - but does it hold true across populations and different aspects of control? We investigate these questions by comparing young and older adults' response to monetary incentives in a task that allows simultaneous assessment of multiple aspects of controlled attention.

Most studies of age differences in incentive-cognition effects have examined reinforcement learning and decision-making, rather than attention. The patterns differ for anticipation and response versus learning the value of different choices (see review by Samanez-Larkin & Knutson, 2015). Older adults are similar to young adults in their arousal ratings and neural responses to anticipated gains, actual gains, and actual losses, but have reduced arousal and neural responses to anticipated losses. In contrast, when learning and updating representations of the values associated with different decisions, older adults are slower and more error-prone, regardless of valence (gain or loss). It is not clear whether these findings are due to differences in cognitive control, but they suggest that age differences in incentive processing may interact with valence and the type of cognitive process.

In contrast to the established literature on age-incentive interactions in learning and memory, studies of these effects on attention and online processing are sparse and somewhat inconsistent, potentially due to the disparate incentive structures and types of attention tested across studies. For example, older adults have been found to be both more and less sensitive to incentive cues and their valence compared to young adults (e.g., Di Rosa et al., 2015; Houvenaghel et al., 2016; Schmitt, Ferdinand, & Kray, 2015; Pachur et al., 2017; Touron and Hertzog, 2009, Westbrook et al., 2013; Williams et al., 2017). Similar to the learning domain, when age differences are found, older adults usually have lower responsivity (less difference compared to a no-incentive baseline) to loss. This pattern is often explained by assuming that older adults minimize attention and emotional responsivity to negative information, in accordance with the "positivity effect" – an age-related tendency to enhance attention and memory for positive information, and reduce it for negative information (Mather et al., 2005).

The research assistants in many aging labs would find that explanation quite surprising. Most of them would testify that in their experience, older adults are much more motivated than young adults to perform well on cognitive tasks and more upset by errors and negative feedback. Self-report data in some mind-wandering studies also indicate that older adults are more motivated than young adults to stay focused on the task and perform well (e.g., Frank, Nara, Zavagnin, Touron, & Kane, 2015). Likewise, Lumosity users who complete at least 25 sessions are older than those who do not (Sternberg et al., 2013), indicating a strong motivation to maintain cognitive performance. The value older adults place on maintaining cognition may make them more, rather than less, responsive to negative information when it concerns their own performance rather than external stimuli (words, pictures, events). Ironically, this increased responsivity may cause them to lose motivation and disengage from the task, leading to further errors (Charles, 2010; Hess, 2014; Zacher et al., 2016). This pattern is seen in the workplace, where older adults are more upset by and less likely to correct errors (Birdi & Zapf, 1997).

The contradictions between workplace and laboratory studies may be due to differences in incentive structure and type of attentional demand. In the workplace and other real-world situations (reading this paper, writing your own, driving without getting lost or in an accident), the incentive often applies to the entire situation, and the environment does not supply many cues to stimulus-driven, reactive attention. This places heavy demands on goal-driven, self-directed attentional focus. In contrast many laboratory attention tasks use incentive cues on every trial, targets that are perceptually different from nontargets, frequent probes, and demands for speeded responses, all of which may provide bottom-up, stimulus-driven support to attention, increase engagement in the task, and reduce mind-wandering (Ralph et al., 2016; Wilson et al., 2016). Older adults are more reliant on bottom-up stimulus cues, environmental support for attention, and reactive responses to probes (Craik & Byrd, 1982; Lindenberger & Mayr, 2014; Paxton et al., 2008). These factors may have reduced the sensitivity of previous studies to incentive effects in older adults.

To create a more ecologically-valid test, we used the same incentive condition across the entire session, and a task in which target detection depends heavily on goal-directed attention and for which misses have been associated with neural and self-report measures of disengaged attention and mind-wandering. This task also assesses the degree to which attention is sustained over time and resistant to external distractors, but based on previous research those measures were not expected to be as closely related to mind-wandering (Berry, Demeter et al., 2014; Berry, Li, et al., 2014) or sensitive to incentive (e.g., Estermann et al., 2014; Hickey et al., 2010). Our results suggest that "paying attention" – especially penalizing poor attention – may decrease attentional focus and increase mind-wandering in older adults.

Methods

All methods, materials, and procedures were approved by the University of Michigan Institutional Review Board.

Participants

Ninety-six young adult and 96 older adult participants were included in the final analysis. An *a priori* power analysis conducted in G*Power 3.1.9.2 (Faul et al., 2007) indicated that a total sample size of n = 158 (26 subjects per group) would be required to detect the critical Age X Incentive interaction at a moderate effect size; we increased this to n = 32 per group (total n = 192) based on the results of our pilot study (see Supplemental Materials).

Young adults (60 female, mean age = 20.04 years, range 18-25) were students recruited from the University of Michigan. Older adults (57 female, mean age = 69.88, range 60-83) were recruited from the Ann Arbor community. All participants received $10 per hour for their participation. Participants in each age group were randomly assigned to one of three incentive conditions: control (no performance incentive), gain condition (potential to earn up to $20 reward for good performance) and loss condition (start with $20, lose 20 cents per error). Participants were screened to ensure physical and psychological health with no history of anxiety, depression, ADHD, or head injury, and no use of medications that affect cognition. Consistent with usual procedures in our lab, the Extended Range Vocabulary Test Version 3 (ERVT; Educational

Testing Service, 1976) was used as a screen for participants who might not understand the instructions or were generally unmotivated; a minimum score of 9 out of a possible 48 was required. Data from individuals with overall very poor performance on the computer task (hit rate below 40% during the first minute of the No Distractor condition, or false alarms larger than 3 standard deviations above the mean) indicating a failure to understand or engage in the task were excluded. For older adults, a Mini Mental State Examination score (MMSE; Cockrell & Folstein, 1988) of 27 or greater was required (see Table 1 for demographic information; Supplemental Materials Table 6 for exclusions by criterion).

Table II-1 Demographic information and self-reported measures

Demographic information and self-reported difficulties with attentional control in everyday life (Poor Attentional Control scale; PAC; see text for details).

	Young Control (n = 32)	**Young Gain** (n = 32)	**Young Loss** (n = 32)	**Old Control** (n = 32)	**Old Gain** (n = 32)	**Old Loss** (n = 32)
Age						
mean	20.09	19.66	20.38	70.38	68.22	71.03
SD	*1.30*	*1.73*	*1.38*	*5.91*	*5.48*	*7.42*
Years of Education						
mean	14.56	14.56	14.86	17.12	17.88	16.73
SD	*1.19*	*1.66*	*1.29*	*2.95*	*2.04*	*2.28*
ERVT						
mean	19.47	21.37	21.71	31.48	34.59	31.50
SD	*6.21*	*6.30*	*6.35*	*7.07*	*5.85*	*10.88*
PAC Mind-Wandering						
mean	14.38	14.09	14.41	12.34	12.75	11.66
SD	*4.03*	*3.71*	*3.46*	*2.48*	*2.38*	*3.08*
PAC Boredom						
mean	13.34	12.97	13.81	11.03	11.16	11.22
SD	*3.46*	*3.96*	*3.37*	*3.15*	*2.49*	*2.70*
PAC Distractibility						
mean	15.63	14.53	14.84	13.59	13.28	13.34
SD	*4.02*	*3.88*	*3.76*	*4.41*	*3.62*	*3.29*

Materials

Continuous Temporal Expectancy Task (CTET) with Video Distractor

See Figure 1 for an illustration of the task and experimental manipulation. As described by O'Connell and colleagues (2009), the CTET was designed to assess lapses of sustained attention and the decline of attentional performance across time, and different EEG signatures are associated with short-term lapses of attention (immediately before a missed target) versus longer-term declines of attention over time. Our lab has modified the CTET to include a video distractor condition (Berry, Li, et al., 2014) and likewise demonstrated dissociations between the different aspects of attention measured by the task. Of particular relevance to the present study, overall target detection performance is affected by modality manipulations that influence the degree to which detection depends on goal- versus stimulus-driven attention and correlates with self-reported difficulties keeping attention focused (mind-wandering), whereas vulnerability to distraction is affected by genetic and pathological conditions affecting the cholinergic system and correlates with self-reported vulnerability to distraction in everyday life (Berry, Demeter et al., 2014; Berry, Lin, et al. 2014, Kim et al., submitted).

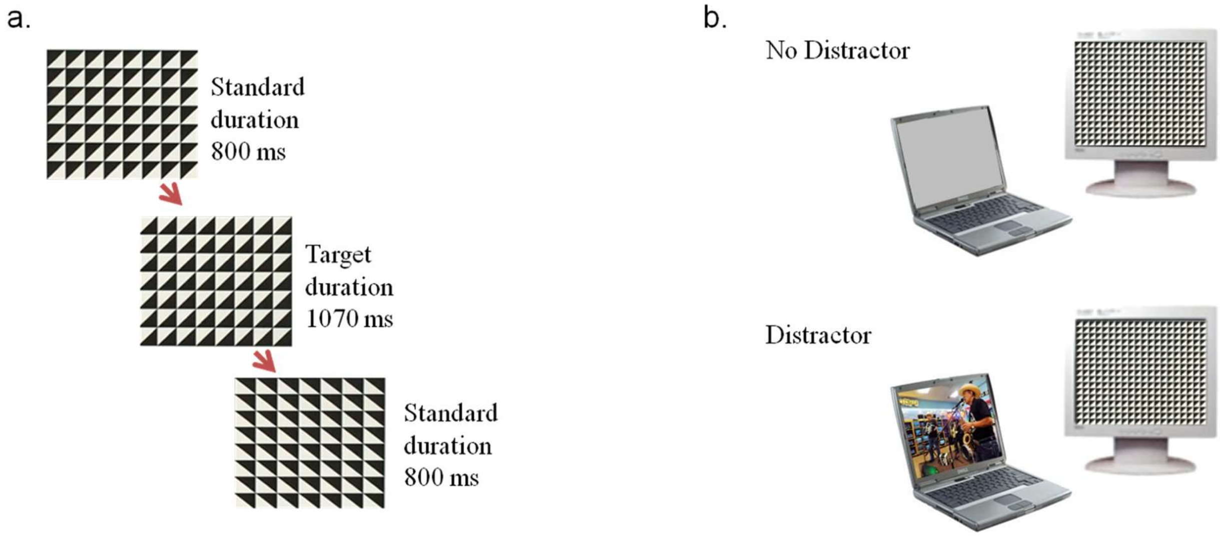

Figure II-1 Continuous temporal expectancy task (CTET) with distraction

a. Participants viewed a grid that typically rotated every 800 ms (90, 180, or 270° rotation, randomly intermixed) and were to press the spacebar in response to the longer-duration target (1070ms). b. The distractor manipulation was implemented using a laptop computer oriented 32° to the left of the task computer, and 65 cm from the participant. In the No Distractor condition, the laptop was silent and displayed a grey screen. In the Distractor condition, the laptop played a series of 30 second video clips, including the audio component.

The main task (CTET) was presented on a Dell PC computer using E-prime version 2.0.8.90 (Psychology Software tools; http://www.pstnet.com/eprime.cfm). During the task, a black and white grid with squares divided diagonally into halves rotated randomly at 90, 180, or 270 degrees at a standard interval of 800 ms, with occasional longer target intervals of 1070 ms. (Figure 1). Participants were instructed to monitor the duration of rotations and press the space bar when they detected the target (longer duration rotation). Before beginning the experiment, participants were given 6 practice runs (3 targets each). To ensure that participants understood the task, the duration difference between standard trials and target trials was exaggerated during the first practice (standard: 800msec; target: 1600). The duration difference for the remaining 5 practice runs was identical to testing runs. Participants had to achieve 100% on at least one of these 5 practice runs in order to proceed to the experiment. The experiment had 10 testing runs (4 min each) with 24 targets per run. Stimuli were presented in a pseudo-randomly intermixed fashion, such that the number of standard trials between two targets ranged from 7 to 17 trials (with an average of 10 standard trials intervening between targets). A correct response (hit) was recorded if participants responded within 2.46s following the target offset. Responses outside this time window were coded as false alarms. At the end of each run, participants were given feedback on their performance and took a one-minute break.

The distractor manipulation created by our lab was implemented on a laptop computer to the left of the main task computer. During No Distractor runs, the laptop presented a grey screen and remained silent. During Distractor runs, the laptop played a series of 30-second video clips with audio. Clips were screened to ensure that they did not contain music or other strong rhythmic components that could influence timing performance. For each participant, half of the runs were in the No Distractor condition, and half were in the Distractor condition, interleaved. Half of the participants in each Age X Incentive group started with a No Distractor run, the other half with a Distractor run. No Distractor and Distractor runs alternated, and their order was counterbalanced across participants.

For participants in the incentive conditions, the task was identical with the addition of a monetary incentive, which participants were informed about after they completed the practice. In the gain condition, participants were told that they could earn up to a $20 bonus based on task performance, but that 20 cents would be deducted from this amount for each error (either missing a target or making a false alarm). Reward earned during the trial was placed on the table after the feedback screen was displayed. The instructions for the loss procedure were the same, with the exception that in this case twenty dollars were placed in front of the participant at the beginning of the task, and the amount was reduced as needed at the end of each run.

Questionnaires

Poor Attentional Control (PAC) scale. Participants rated 36 statements about cognition and attention in everyday life from the Imaginal Processes Inventory (Singer & Antrobus, 1970) as to how true each statement was of them (1 = not all true of me; 5 = very true of me). As in previous papers from our group (Berry, Demeter, et al., 2014; Berry, Li, et al., 2014; Kim et al., 2017, submitted), final analyses focused on the 15 items from the mind-wandering, boredom, and distractibility subscales, which make up the Poor Attentional Control (PAC) scale identified in a factor analysis (Huba, Singer, Aneshensel, & Antrobus, 1982). This scale was used as the trait measure of attentional function in everyday life, and thus was administered before participants completed the computer task.

Surprise quiz and post-experiment questionnaire. After the computer task, participants were given a quiz consisting of 15 multiple-choice questions to test their memory of the distractor video content, and a 5 question post-experiment questionnaire. The post-experiment questionnaire asked participants to rate their level of mind-wandering, boredom, and distractibility during the task based on a scale from 1 to 5. The questions were created with similar form and content to items from the PAC. As in our prior work (Berry, Demeter, et al., 2014; Berry, Li, et al., 2014), question 4 ('I had difficulty in keeping my attention focused on this long tedious task') was used as a state measure of mind-wandering; question 3 ('I was easily bored during this task.') measured boredom; and question 5 ('No matter how hard I tried to concentrate, I felt easily distracted by the video playing.') measured distractibility. These questions were used as state attention measures; that is, attention during the task.

Analysis

Analyses were conducted using IBM SPSS version 24. As in prior work, (Berry, Demeter, et al., 2014; Berry, Li, et al., 2014; O'Connell et al., 2009), average minute-by-minute hit rates (correct detections of target) were the primary dependent variable for the CTET. Analyses of signal detection measures yielded similar results. (See Supplemental Materials Table 1). Likewise replicating previous studies by our lab and others, there were no "run" effects (increasing or decreasing performance across the session); analyses below therefore report the session average for each condition. To examine interactions between Age Group and the different experimental factors, data were analyzed in a mixed-design ANOVA with the between-subject factors Age Group (young, old), and Incentive (Control, Gain, Loss) and the within-subject factors Time (minute 1, 2, 3, and 4) and Distractor Condition (No distractor, Distractor), with follow-up ANOVA and two-sided Dunnett's t-tests (contrasting each incentive condition with the control condition; note that this test in SPSS provides the p values and confidence intervals (CI) but not the t value per se) used to contrast conditions within each age group. For the main effect of Time and interactions involving this factor, reported results are from the linear trend analyses. For analyses including within-subjects factors, the Greenhouse-Geisser correction was applied when sphericity was violated, and corrected degrees of freedom (rounded to the nearest integer for easier reading), *p*, and *F* values are reported below. Effect sizes for repeated measures were determined using generalized eta squared (η^2_G , Olejnik & Algina, 2003). This calculation gives smaller numbers than the partial eta squared that is often reported, but is preferred as it reduces error when comparing across studies (Bakeman, 2005; Fritz, Morris, & Richler, 2012).

For the questionnaire measures of attention (PAC score and corresponding post-experiment questions), a multivariate test was used with Age and Incentive as fixed factors, and the three dimensions (mind-wandering, boredom, distraction) as the dependent variables. Performance on the post-experiment quiz was analyzed using a univariate ANOVA with Age and Incentive as the fixed factors. As for the CTET, follow-up analyses were conducted within each age group with incentive conditions contrasted against the control condition using Dunnett's t-test.

Results

Negative Incentive Reduces Attentional Focus in Older Adults

Statistical analyses reported here focus on effects involving the incentive manipulation; full ANOVA results for the CTET are reported in Supplemental Materials Table 2. We replicated standard effects of time-on-task declines, reduced performance under distraction, and a greater impact of distraction on older adults than young adults.

The critical results are illustrated in Figure 2. The incentive conditions numerically improved the performance and subjective attention of young adults, especially in the gain condition, but reduced the performance and subjective attention of older adults, especially in the loss condition. As described above, for each age group we conducted a follow-up ANOVA with the between-subjects factor Incentive and the within-subjects factors Distraction and Time, and used post-hoc two-sided Dunnett's t-tests to compare the control condition to each incentive condition. For young adults, there were no main effects or interactions with the Incentive condition, all $p > .250$; likewise the post-hoc tests did not show significant differences between the control group and either incentive group, both $p > .250$. In contrast, for the older adults, the main effect of Incentive was marginal, $F(2, 93) = 2.95$, $p = .057$, $\eta^2_G = .051$, with the Dunnett's t-test showing that performance in the gain condition was numerically but not statistically lower than the control condition ($p > .250$, CI = -.121 - .059), whereas performance in the loss condition was significantly worse than performance in the control condition ($p = .036$, CI = -.185 - -.005). This indicates that the marginal status of the main effect in the overall ANOVA is mostly like due to both the gain and loss conditions being numerically lower than the control condition (and thus both contributing to the grand mean). (See Supplemental Materials for similar effects of the loss incentive in our pilot dataset.)

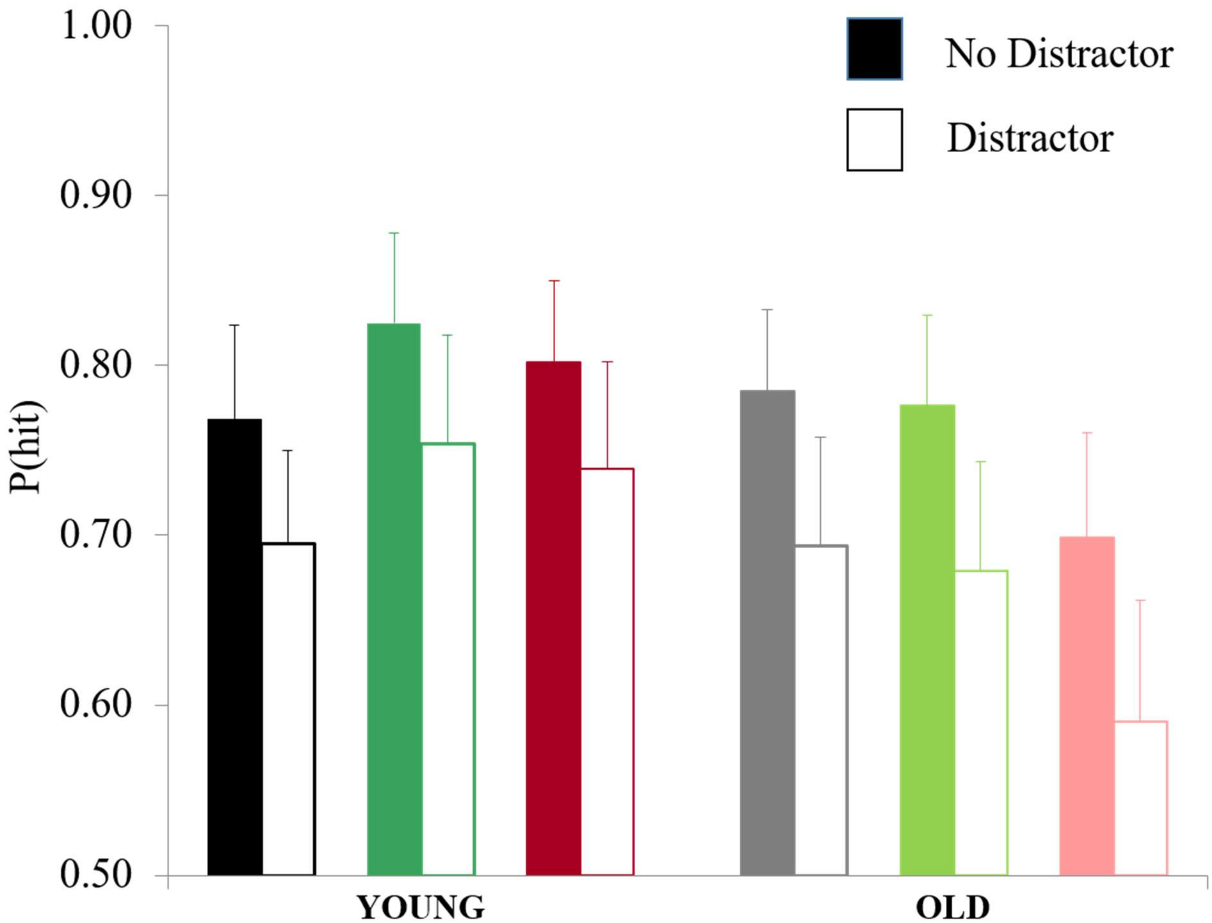

Figure II-2 Loss incentive reduces the performance of older adults.

Different colors (control = black, green = gain, red = loss) and shades (dark = young adults, light = older adults) are used to highlight the different conditions. Error bars represent confidence intervals (between-subjects; note that the distraction manipulation is within-subjects). Results are collapsed across the Time factor for clarity; see Table 1 in Supplemental Materials for those numbers. While incentive tended to improve the performance of young adults, especially in the gain condition, it reduced the performance of older adults, especially in the loss condition.

Positive incentive increases subjective attention for young adults, whereas negative incentive decreases subjective attention for older adults

The PAC measures served as a "trait" measure of subjective attention in everyday life. Replicating typical findings (Giambra, 1993; Jackson & Balota, 2012; Maillet & Schacter, 2016), older adults reported lower rates of mind-wandering, boredom, and distraction in everyday life than did young adults, all $F > 8.20$, $p < .001$, $\eta^2_G > .042$. There were no pre-existing differences between the Incentive groups or Age X Incentive interactions on any of these measures, all $F < 1$.

The post-experiment questionnaire measures asked participants about their mind-wandering, boredom, and distraction during the task. In contrast to the lack of differences between the incentive groups for the "trait" (PAC) measures reported above, incentive had opposite effects on young and older adults' experience during the task itself (Age X Incentive interactions for mind-wandering, $F(2, 186) = 3.88$, $p = .022$, $\eta^2_G = .040$; boredom, $F(2, 186) = 4.42$, $p = .013$, $\eta^2_G = .045$; distraction, $F(2, 186) = 2.99$, $p = .052$, $\eta^2_G = .031$). As seen in Figure 3, the results, especially for the mind-wandering measure, generally replicated the pattern seen for target detection in the CTET. For young adults, the incentive conditions tended to decrease mind-wandering and boredom during the task, with effects reaching statistical significance for the gain condition (mind-wandering: mean difference = -.844, $p = .006$, CI = -1.463 - -0.224; boredom: mean difference = -.938, $p = .009$, CI: -1.67 - - 0.210). Older adults showed the opposite pattern, and in particular an increase in mind-wandering in the loss condition (mean difference .656, $p = .044$, CI = .016 – 1.296). Incentive did not affect the degree to which participants reported being distracted by the video for either group, suggesting that manipulating incentives primarily affected task focus and engagement, rather than impacting all executive-control functions (including distractibility) equally. The surprise quiz for memory of video content replicated standard effects of greater recognition memory for young than older adults, $F(1, 186) = 86.65$, $p < .001$, $\eta^2_G = .318$. There were no effects of incentive or age X incentive interactions on the surprise quiz, all $F < 1$. (See Table 3 in Supplemental Materials for full results.)

In short, the “trait” measures of self-reported mind-wandering, boredom, and distractibility in everyday life replicated typical findings in the literature of higher ratings by younger than older adults, but the incentive conditions had different effects on attention (but not memory) for young and older adults: Positive incentive decreased mind-wandering (and boredom) for young adults, whereas negative incentive increased mind-wandering for older adults.

Statistically controlling for subjective mind-wandering eliminates incentive effects on performance

For both young and older adults, the incentive effects on the CTET task primarily impacted the measure thought to index focused attention, and incentive effects on the subjective ratings primarily impacted the measure of mind-wandering. Therefore, we next asked whether those subjective differences in mind-wandering might account for the incentive effects we found on task performance. To test this hypothesis, we repeated the CTET ANOVA analyses, this time including ratings of mind-wandering during the task as a covariate. In the analysis including Age, the effect of the mind-wandering covariate was significant, $F(1, 185) = 21.87$, $p < .001$, $\eta^2_G = .090$, and the previously-observed Age X Incentive interaction was eliminated, $F(2, 185) = 1.57$, $p = .210$, $\eta^2_G = .014$. Likewise, for the analysis conducted within the older adult age group, the mind-wandering covariate was statistically significant, $F(1, 92) = 15.48$, $p < .001$, $\eta^2_G = .123$, but the previously-observed effect of Incentive was not, $F(2, 92) = 1.26$, $p = .288$, $\eta^2_G = .022$, and the pairwise comparison between the control condition and the loss condition was likewise no longer significant after controlling for mind-wandering, $p = .357$, CI = -.033 - .154. These results suggest that an increase in mind-wandering under the loss incentive may account for older adults’ poor performance under these conditions.

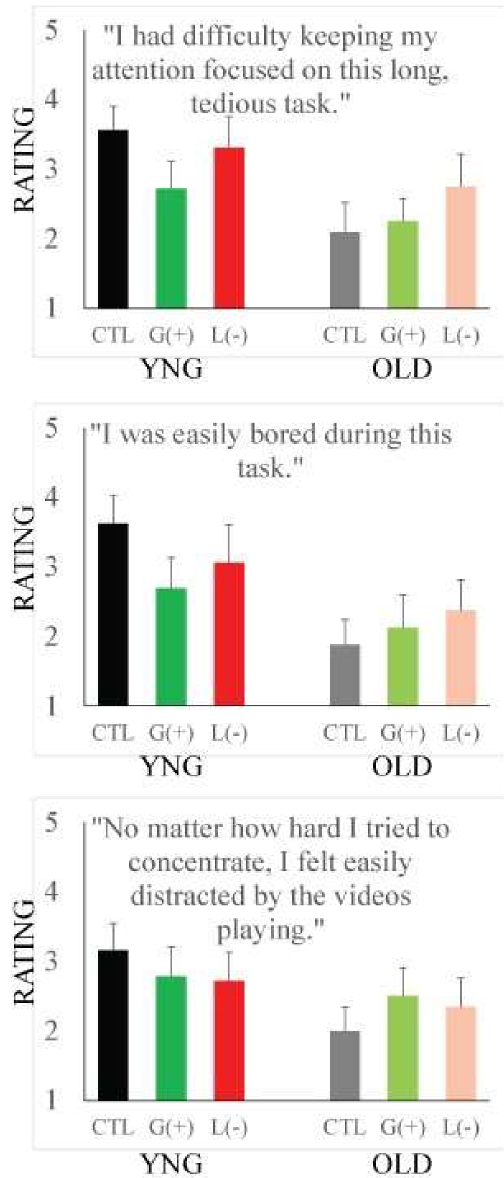

Figure II-3 Incentive decreased mind-wandering and boredom in young adults, but increased it in older adults.

Distraction from the videos was not affected for either group. See text for statistics.

Discussion

We began this paper by asking how incentives might affect your attention to this paper. Our results suggest that the answer may depend on how old you are: Young adults showed little effect or a slight benefit, whereas older adults had an increase in mind-wandering and a corresponding reduction in performance – especially when there was money to be lost.

These results cannot be simply explained as "older adults don't care as much about the money": Older adults were more, not less, sensitive than young adults to the incentive manipulation. Furthermore, there were qualitative differences, such that the patterns for the two age groups were diametrically opposed: Young adults had better performance and less mind-wandering under incentive, especially in the gain condition, but older adults had decreased performance and increased mind-wandering under incentive, especially in the loss condition.

Our results contradict the heuristic that older adults are less responsive than young adults to losses. Instead, losses, not gains, had an especially strong effect on the performance of the older adults. This might at first seem to contradict the predictions of Socioemotional Selectivity Theory and typical findings of a "positivity effect" in aging (Carstensen, Isaacowitz, & Charles, 1999; Mather & Carstensen, 2005). However, a closer examination suggests that this is not necessarily the case. Most studies demonstrating the typical positivity effect have varied the emotional valence of external stimuli (e.g., words, pictures, faces). When faced with a negative experience such as interpersonal conflict or other daily hassles (e.g., waiting in lines) – or in this case, losing money as a result of errors – older adults tend to disengage, and to do so more rapidly than young adults (see review by Charles, 2010). Like the reduced attention older adults show to negative external stimuli, this rapid disengagement from negative experiences is interpreted as a strategic effort to regulate emotions. However, in attention-demanding situations, it may come with the cost of reduced performance and further losses.

Consistent with a "disengagement" interpretation, the effects of the loss incentive condition on older adults appear to be specifically to their focus of attention on the task, as indicated both by performance on the computerized task and participants' ratings of mind-wandering and boredom. By comparison, although both distraction and time-on-task increased errors, neither interacted with incentive (see also Estermann et al., 2014; Hickey et al., 2010). The control and gain conditions also presented error feedback, suggesting that it was not errors per se but rather the negative experience of losing money as a result of errors that decreased performance in the loss-incentive condition. That the different aspects of attention assessed by the task are dissociable replicates our previous work: Genetic and pathological conditions affecting the cholinergic system selectively increase vulnerability to distraction (Berry et al., 2014a; Kim et al., submitted), whereas overall performance is influenced by manipulations of the degree to which target detection relies on stimulus-driven versus goal-driven attention (Berry et al., 2014b).

Goal-driven attention is crucial to target detection in the present task because the target does not visually differ from the standard. Instead performance requires accurate representations of duration, which depend heavily on focused attention (see O'Connell et al., 2009). In addition, the incentive manipulation was implemented on a task-wise, rather than trial-wise basis. These features make the task similar to many real-world situations: While your attention to this paper receives some support from perceptual cues such as paragraph breaks, for the most part it relies on goal-driven attention, and although some sentences are more interesting than others, your judgment of whether reading the paper was rewarding will depend on your impression overall.

These factors may also explain why results from previous laboratory studies have been inconsistent. Many implemented incentive on a trial-wise basis and/or used targets perceptually different from nontargets, providing cues to stimulus-driven attention. Jimura et al. (2010) found that although there was a smaller, transient boost for rewarded trials versus unrewarded ones, the major benefits of incentive on behavioral and neural measures of cognitive control were tonic, affecting even unrewarded trials. These incentive-context effects would not be detectable in studies manipulating incentive only on a trial-by-trial basis.

Furthermore, Jimura et al. (2010) found that incentive-context effects primarily affected measures of proactive, goal-driven attention. As described above, many previous studies of age differences in incentive effects have used targets that provide cues to stimulus-driven attention, reducing the reliance on goal-driven attention and thus potentially reducing their sensitivity to these incentive-context effects. Interestingly, while gain incentives may be more effective in boosting transient, trial-specific control, loss incentives have more global effects (Paschke et al., 2015). The different timescales of gain versus loss incentive effects may contribute to findings of preserved gain effects but a lack of loss effects for older adults in studies with trial-wise incentives, and loss-specific dissociations between performance and trial-wise neural measures of incentive effects (e.g., Williams et al., 2017).

Fully testing this potential explanation will require parametric manipulations of target salience and incentive structure beyond the scope of the current paper. Another remaining question is the pathway(s) by which incentive manipulations have their effects: Does the drop in performance under loss incentive for older adults stem from increased anxiety about performance and physiological over-arousal that disrupts cognition, performance-related thoughts that distract attention from the task, or a general loss of motivation and engagement that might affect even non-cognitive tasks?

The loss of motivation and engagement explanation would be most consistent with other findings suggesting that older adults rapidly disengage from negative experiences (see discussion by Charles, 2010), and receives indirect support from several other findings. Low motivation has been linked to more task-unrelated thoughts (Seli et al., 2015; Unsworth & McMillan, 2013), and Selective Engagement Theory suggests that age-related increases in cognitive costs decrease older adults' motivation to engage in mentally demanding activities (Hess, 2014). A physiologic measure of motivation and engagement, systolic blood pressure (SBP) initially increases with mental demand but declines when demand surpasses the ability to maintain performance or when the effort to do so is no longer worthwhile. When these SBP changes are scaled as a function of subjective mental demand and effort, both the initial rise and subsequent drop were steeper in older adults (Ennis et al., 2013; Hess et al., 2016). Attaching monetary costs to mental demand may increase older adults' sensitivity to cognitive costs, increasing their mind-wandering and boredom in the loss condition; the statistical elimination of incentive effects on performance by controlling for mind-wandering supports this interpretation.

Notably, the increase and subsequent decrease with mental demand observed for SBP is also seen in the right middle/inferior frontal gyrus region linked to incentive-attention interactions by Jimura et al. (2010) and Paschke et al. (2015), and is likewise shifted in older adults and patients with schizophrenia (see review by Lustig & Sarter, 2016). Data from both humans and rodent models suggests that this pattern, termed CRUNCH (Compensation Related Utilization of Neural Circuits Hypothesis; Reuter-Lorenz & Cappell, 2008) in the aging literature, reflects right prefrontal cortex's role as a critical hub for interactions between the neural systems mediating goal-directed attention, motivation, and arousal (Berry et al., 2017; Lustig & Sarter, 2016). Testing whether these two phenomena (CRUNCH and SBP effects) are related, and how they are affected by incentives, may help improve interventions, especially for populations associated with reduced goal-driven attention and altered motivational processing compared to young adults.

The present study takes a first step in this direction by demonstrating important age differences in the effects of incentive: For older adults, don't pay – or at least don't penalize – attention! Establishing the neural and physiological basis of these effects will require further research, but meanwhile the present results may inform efforts to improve older adults' attentional performance in the workplace and other aspects of everyday life

Appendix A.

Additional results from main-text experiment

Table II-2 CTET performance in each group

Means and confidence intervals for attentional performance in each group (hits, false alarm, d', and bias)

	Time							
	Minute 1		Minute 2		Minute 3		Minute 4	
Performance	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Young control no distractor hits (%)	82.08	[77.03, 87.12]	77.79	[71.77, 83.81]	75.67	[69.35, 81.99]	72.08	[64.72, 79.44]
Young control distractor hits (%)	75.68	[70.53, 80.82]	72.70	[66.52, 78.89]	66.25	[59.82, 72.69]	63.84	[57.50, 70.17]
Young gain no distractor hits (%)	87.82	[83.39, 92.26]	85.19	[80.33, 90.05]	79.59	[72.94, 86.25]	77.14	[71.08, 83.20]
Young gain distractor hits (%)	81.53	[76.31, 86.74]	77.25	[71.18, 83.32]	74.80	[66.89, 82.71]	68.01	[60.62, 75.40]
Young loss no distractor hits (%)	86.41	[82.04, 90.78]	79.90	[74.44, 85.36]	80.43	[75.86, 84.99]	74.11	[67.67, 80.55]
Young loss distractor hits (%)	79.39	[73.15, 85.62]	77.73	[71.63, 83.83]	70.55	[63.27, 77.83]	68.26	[61.12, 75.40]
Old control no distractor hits (%)	84.56	[80.78, 88.33]	80.16	[74.54, 85.79]	75.29	[69.63, 80.94]	74.63	[68.32, 80.93]
Old control distractor hits (%)	70.29	[64.16, 76.42]	73.37	[67.23, 79.52]	70.29	[63.67, 76.91]	64.10	[56.19, 72.01]
Old gain no distractor hits (%)	79.64	[74.09, 85.19]	78.56	[72.81, 84.31]	74.40	[68.40, 80.40]	68.88	[62.31, 75.46]
Old gain distractor hits (%)	72.87	[66.88, 78.87]	68.35	[61.42, 75.28]	64.22	[57.52, 70.92]	61.11	[54.17, 68.06]

Old loss no distractor hits (%)	74.75	[68.82, 80.67]	72.84	[66.09, 79.59]	69.19	[62.82, 75.55]	63.01	[55.42, 70.60]
Old loss distractor hits (%)	64.01	[56.37, 71.65]	61.77	[54.51, 69.04]	58.81	[49.94, 67.69]	52.07	[44.19, 59.94]
Young control no distractor FA (%)	1.07	[0.09, 2.04]	1.38	[0.20, 2.57]	1.16	[0.18, 2.14]	1.32	[0.24, 2.40]
Young control distractor FA (%)	1.28	[0.22, 2.34]	1.66	[0.30, 3.02]	1.63	[0.39, 2.86]	1.60	[0.37, 2.83]
Young gain no distractor FA (%)	0.33	[0.23, 0.43]	0.37	[0.21, 0.53]	0.32	[0.19, 0.45]	0.35	[0.28, 0.42]
Young gain distractor FA (%)	0.34	[0.23, 0.44]	0.36	[0.25, 0.46]	0.33	[0.22, 0.44]	0.45	[0.31, 0.60]
Young loss no distractor FA (%)	0.43	[0.21, 0.64]	0.33	[0.14, 0.52]	0.28	[0.19, 0.38]	0.49	[0.32, 0.67]
Young loss distractor FA (%)	0.30	[0.22, 0.38]	0.41	[0.22, 0.59]	0.35	[0.23, 0.46]	0.51	[0.35, 0.67]
Old control no distractor FA (%)	1.81	[0.82, 2.80]	1.47	[0.64, 2.30]	0.97	[0.47, 1.47]	1.30	[0.66, 1.94]
Old control distractor FA (%)	2.35	[1.12, 3.57]	1.78	[0.74, 2.83]	1.50	[0.69, 2.30]	1.39	[0.41, 2.36]
Old gain no distractor FA (%)	1.36	[0.73, 1.99]	1.15	[0.51, 1.79]	1.02	[0.48, 1.55]	1.11	[0.66, 1.57]
Old gain distractor FA (%)	1.34	[0.81, 1.86]	1.38	[0.78, 1.98]	0.90	[0.56, 1.24]	1.03	[0.52, 1.55]
Old loss no distractor FA (%)	1.52	[0.49, 2.54]	1.25	[0.40, 2.11]	1.12	[0.32, 1.92]	1.07	[0.42, 1.73]
Old loss distractor FA (%)	1.44	[0.42, 2.46]	1.58	[0.60, 2.55]	1.02	[0.40, 1.63]	1.28	[0.34, 2.21]
Young control no distractor d'	3.68	[3.40, 3.97]	3.44	[3.11, 3.76]	3.39	[3.11, 3.67]	3.22	[2.91, 3.53]

Young control distractor d'	3.37	[3.06, 3.68]	3.17	[2.87, 3.47]	2.91	[2.66, 3.17]	2.85	[2.56, 3.13]
Young gain no distractor d'	4.13	[3.89, 4.38]	4.00	[3.75, 4.25]	3.81	[3.52, 4.10]	3.62	[3.38, 3.86]
Young gain distractor d'	3.83	[3.59, 4.08]	3.65	[3.38, 3.93]	3.63	[3.32, 3.93]	3.29	[2.98, 3.60]
Young loss no distractor d'	4.01	[3.75, 4.28]	3.79	[3.54, 4.04]	3.81	[3.58, 4.04]	3.45	[3.16, 3.74]
Young loss distractor d'	3.82	[3.53, 4.11]	3.69	[3.40, 3.98]	3.47	[3.17, 3.76]	3.23	[2.98, 3.48]
Old control no distractor d'	3.54	[3.26, 3.82]	3.45	[3.13, 3.77]	3.32	[3.08, 3.57]	3.26	[2.95, 3.57]
Old control distractor d'	2.87	[2.56, 3.18]	3.08	[2.79, 3.37]	3.03	[2.75, 3.32]	2.89	[2.59, 3.19]
Old gain no distractor d'	3.43	[3.12, 3.74]	3.42	[3.13, 3.72]	3.28	[3.02, 3.55]	3.06	[2.74, 3.37]
Old gain distractor d'	3.10	[2.81, 3.39]	2.95	[2.66, 3.25]	2.94	[2.69, 3.20]	2.83	[2.56, 3.09]
Old loss no distractor d'	3.24	[2.93, 3.54]	3.27	[2.94, 3.60]	3.14	[2.85, 3.44]	2.87	[2.60, 3.15]
Old loss distractor d'	2.88	[2.58, 3.18]	2.76	[2.47, 3.05]	2.84	[2.51, 3.18]	2.55	[2.26, 2.84]
Young control no distractor bias	0.91	[0.85, 0.96]	0.90	[0.85, 0.94]	0.92	[0.88, 0.96]	0.91	[0.87, 0.96]
Young control distractor bias	0.92	[0.88, 0.96]	0.91	[0.86, 0.96]	0.93	[0.88, 0.97]	0.94	[0.90, 0.98]
Young gain no distractor bias	0.90	[0.87, 0.94]	0.89	[0.82, 0.96]	0.94	[0.92, 0.96]	0.94	[0.90, 0.97]
Young gain distractor bias	0.93	[0.90, 0.96]	0.95	[0.93, 0.97]	0.95	[0.92, 0.97]	0.96	[0.93, 0.98]
Young loss no distractor bias	0.91	[0.88, 0.94]	0.95	[0.93, 0.97]	0.95	[0.93, 0.97]	0.95	[0.93, 0.97]
Young loss distractor bias	0.93	[0.91, 0.96]	0.93	[0.90, 0.97]	0.96	[0.94, 0.98]	0.95	[0.93, 0.97]
Old control no distractor bias	0.81	[0.73, 0.88]	0.88	[0.83, 0.93]	0.92	[0.88, 0.96]	0.90	[0.85, 0.94]

Old control distractor bias	0.89	[0.85, 0.93]	0.89	[0.84, 0.93]	0.92	[0.88, 0.95]	0.95	[0.93, 0.97]
Old gain no distractor bias	0.86	[0.77, 0.95]	0.90	[0.85, 0.95]	0.92	[0.88, 0.97]	0.94	[0.92, 0.97]
Old gain distractor bias	0.91	[0.88,0.94]	0.93	[0.89, 0.96]	0.95	[0.92, 0.98]	0.96	[0.95, 0.98]
Old loss no distractor bias	0.90	[0.85, 0.95]	0.91	[0.86, 0.96]	0.95	[0.93, 0.97]	0.95	[0.93, 0.97]
Old loss distractor bias	0.94	[0.91, 0.97]	0.94	[0.92, 0.97]	0.96	[0.95, 0.98]	0.97	[0.95, 0.98]

T

Table II-3 Summary of ANOVA results for CTET.

Results for the Time factor and interactions involving it use the linear trend analysis.

Source	Sum of Squares	df	F	p	η^2_G
Age	1.64	1	8.59**	.004	.038
Incentive	.46	2	1.20	>.250	.011
A x I	1.18	2	3.08*	.048	.027
Error	35.59	186			
Time	2.60	1	253.01**	< .001	.059
T x A	.0064	1	.62	>.250	<.001
T x I	.017	2	.82	>.250	<.001
T x A x I	.0072	2	.35	>.250	<.001
Error (time)	1.91	186			
Distractor	2.58	1	161.23**	< .001	.058
D x A	.070	1	4.37*	.038	.002
D x I	.0024	2	.076	>.250	<.001
D x A x I	.016	2	.51	>.250	<.001
Error (distractor)	2.98	186			
D x T	.0012	1	.16	>.250	<.001
D x T x A	.012	1	1.63	.203	<.001
D x T x I	.0027	2	.19	>.250	<.001
D x T x A x I	.010	2	.72	>.250	<.001
Error (D x T)	1.33	186			

*p<.05, **p < .01

Table II-4 State (post-experiment) subjective attention, and quiz score for distractor video content.

	Young Control (n = 32)	**Young Gain** (n = 32)	**Young Loss** (n = 32)	**Old Control** (n = 32)	**Old Gain** (n = 32)	**Old Loss** (n = 32)
Exit questionnaire						
1. At times of this task, it was hard for me to keep my mind from wandering.						
mean	3.56	3.13	3.34	2.38	2.66	2.50

	SD	*1.08*	*1.36*	*1.10*	*1.21*	*1.00*	*1.30*
2. (*reverse scored)* During the task, my thoughts seldom drifted from the subject before me.							
	mean	3.38	3.47	3.38	2.63	3.09	3.00
	SD	*1.16*	*1.14*	*1.10*	*1.31*	*1.28*	*1.24*
3. I was easily bored during this task.							
	mean	3.63	2.69	3.06	1.88	2.13	2.38
	SD	*1.13*	*1.23*	*1.50*	*1.01*	*1.31*	*1.21*
4. I had difficulty in keeping my attention focused on this long, tedious task.							
	mean	3.56	2.72	3.31	2.09	2.25	2.75
	SD	*0.95*	*1.11*	*1.23*	*1.17*	*0.92*	*1.30*
5. No matter how hard I tried to concentrate, I felt easily distracted by the videos playing.							
	mean	3.16	2.78	2.71	2.00	2.50	2.34
	SD	*1.08*	*1.18*	*1.14*	*0.95*	*1.14*	*1.15*
Surprise quiz **% correct recognition of distractor content**							
	mean	73.04	69.58	71.04	44.79	46.46	39.37
	SD	*23.37*	*16.24*	*17.32*	*16.78*	*21.45*	*26.36*

Test of correlations reported in prior publications

To enable meta-analyses and test replicability across datasets, we consistently test the same set of correlations across our studies using the video CTET, PAC questionnaires, and post-CTET questionnaire (Berry, Li et al., 2014; Berry et al., 2014; Kim et al., submitted.; with median |r| = .21; range .15 - .67). Below we report the results for the control group to test replication (a priori estimate power estimate indicates n = 61 for .80 power to detect r = .35) , and for the incentive groups to test for potential deviation from the patterns usually seen in our prior studies, which have not incentivized performance. Since the effects of incentive were similar within each age group, we combined the positive and negative conditions for the latter tests. Note that this increases the sensitivity (sample size) for the latter tests, with power = .80 for a $r = .167$ (two-sided test).

We have generally found that correlations between performance in the standard, no-distraction condition of the CTET and self-reported mind-wandering are consistent across studies, whereas correlations with the distractor effect (difference between performance in the standard condition and the distractor condition) are less reliable. This may be due in part to the inherent decrease in reliability when using difference scores. These general findings were also observed in the current control-condition (no-incentive) data set, with $r = -.28$, $p = .026$ for the target-detection/focus of attention measure's correlation with the PAC measure of "trait" mind-wandering in everyday life, and r -.45, $p < .001$ for the correlation with self-reported difficulty keeping attention focused during the task. Both of these effects were reduced or even eliminated by the incentive manipulation, $r = .004$, $p = .97$ for the correlation between performance and PAC mind-wandering, $r = -.18$, $p = .044$ for the correlation between performance and self-reported difficulty keeping attention focused during the task.

For the distractor effect (difference between performance in the standard and distractor conditions of the CTET), the control group showed a marginal correlation, $r = .24$, $p = .05$ for the correlation with the PAC-D measure of distraction in everyday life, but not for self-reported distractibility during the task $r = .13$, $p = .318$ or memory for the distractor videos, $r = -.01$, $p = .952$. These patterns were to some degree reduced or even reversed for the incentive group, at least for the subjective measures: $r = -.24$, $p = .006$ for the correlation with the PAC-D measure of distractibility everyday life, $r = .19$, $p = .03$ for the correlation with self-reported distractibility during the task, and $r = -.03$, $p = .717$ for the correlation with memory for the distractor videos' content.

Pilot experiment results

Prior to the experiment described in the text, we ran a pilot study using young adults from the Psychology Subject Pool and a loss-incentive condition that started at $10 (rather than $20). After completing that study, we realized that comparing subject pool young adults to paid, community-recruited older adults was potentially problematic. As indicated below, in the control condition subject-pool young adults performed worse than older adults and the incentive manipulation showed only trend-level results. We therefore collected new samples of paid young adults for all conditions and older adults for the incentive conditions, using a larger incentive manipulation ($20); this is the study reported in the main text.

The major results from this pilot study are reported below. Several features are worth noting:

1. As in the study reported in the main text, the primary effects of incentive were on the target-detection measure reflecting the focused, goal-directed attention, rather than on distraction or time-on-task effects.
2. Also following the same pattern as the study reported in the main text, the loss-incentive condition tended to improve the performance and decrease self-reported mind-wandering, boredom, and distractibility in the young adults, but to decrease performance and increase the self-report measures of mind-wandering, boredom, and distractibility in the older adults.
3. In the control condition, older adults had significantly better performance overall than did young adults, $F(1,62) = 5.73$, $p = .02$, $\eta^2_G = .076$, whereas in the loss incentive condition,

the performance of the two age groups was nearly identical, $F < .0005$. Critical results are illustrated in Figure 1 and Table 5.

4. Controlling for self-reported mind-wandering (using it as a covariate in the ANOVA model) eliminated the advantage for the older adults in the control condition, $F<1$. This is consistent with the idea that subject-pool young adults are less motivated and more likely to mind-wander than community-dwelling older adults, and that this greater tendency towards mind-wandering plays an important role in performance on the task.

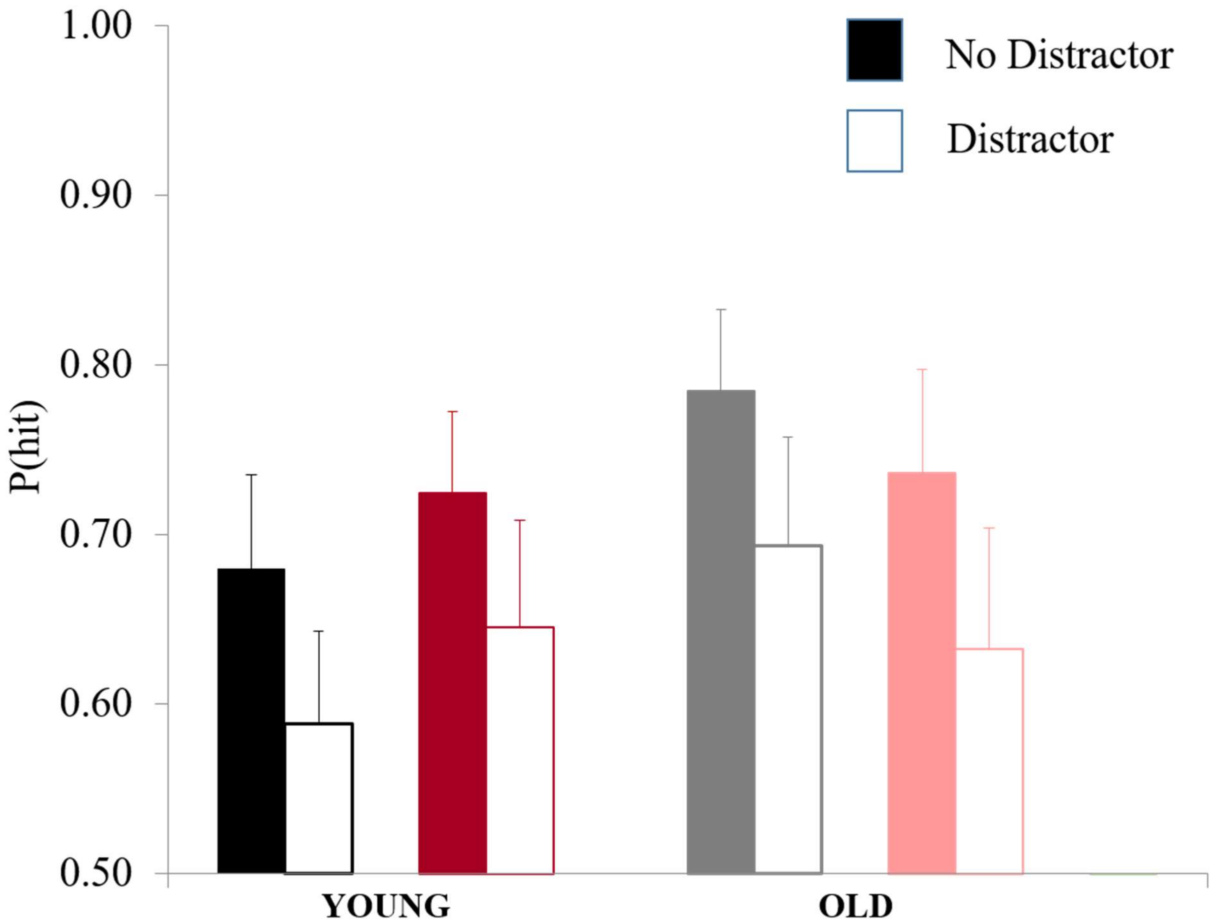

Figure II-4 Older adults outperformed young adults in the control condition, whereas in the loss incentive condition, the performance of the two age groups was nearly identical.

Different colors (control = black, green = gain, red = loss) and shades (dark = young adults, light = older adults) are used to highlight the different conditions. Error bars represent confidence intervals (between-subjects; note that the distraction manipulation is within-subjects). Results are collapsed across the Time factor for clarity.

Table II-5 Pilot study demographic information and self-reported measures.

Pilot study demographic information, self-report of trait (PAC) and state (post-experiment) subjective attention, and quiz score for distractor video content. Young adult subjects were recruited from the Psychology Subject Pool (SP).

		SP Control (n = 32)	**SP Loss** (n = 32)	**Old Control** (n = 32)	**Old Loss** (n = 32)
Age					
	mean	18.63	18.63	70.38	72.03

SD	*.83*	*1.04*	*5.91*	*6.83*
Years of Education				
mean	13.20	13.47	17.12	16.91
SD	*1.24*	*1.22*	*2.95*	*2.84*
ERVT				
mean	19.02	15.88	31.48	31.43
SD	*6.11*	*5.20*	*7.07*	*8.25*
PAC Mind-Wandering				
mean	14.78	14.78	12.34	12.78
SD	*3.84*	*3.65*	*2.48*	*2.89*
PAC Boredom				
mean	13.00	13.31	11.03	11.63
SD	*3.87*	*3.26*	*3.15*	*2.46*
PAC Distractibility				
mean	15.53	15.06	13.59	13.63
SD	*3.48*	*3.46*	*4.41*	*3.17*
Exit questionnaire				
1. At times of this task, it was hard for me to keep my mind from wandering.				
mean	4.03	3.53	2.38	2.41
SD	*.86*	*1.19*	*1.21*	*1.01*
2. (*reverse scored)* During the task, my thoughts seldom drifted from the subject before me.				
mean	3.75	3.00	2.63	2.71
SD	*.88*	*1.16*	*1.31*	*1.14*
3. I was easily bored during this task.				
mean	4.09	3.38	1.88	1.97
SD	*1.09*	*1.34*	*1.01*	*1.12*
4. I had difficulty in keeping my attention focused on this long, tedious task.				
mean	3.84	3.47	2.09	2.31
SD	*1.05*	*1.16*	*1.17*	*.97*
5. No matter how hard I tried to concentrate, I felt easily distracted by the videos playing.				
mean	3.34	2.97	2.00	2.41
SD	*.97*	*1.12*	*.95*	*1.07*
Surprise quiz				
% correct recognition of distractor content				
mean	74.57	77.71	44.79	37.03
SD	*18.42*	*15.48*	*16.78*	*21.40*

Table II-6 Summary of excluded subjects.

Subjects in the Prior Screening Criteria column were those who did not meet health and other screening criteria described in the method section. Subjects in the Poor Performance column were excluded due to overall very poor performance (hit rate below 40% during the first minute of the No Distractor condition, and false alarms larger than 3 standard deviations above the mean). Subjects in the Others column were excluded due to reasons including missing data and technical errors (e.g. participant failed to follow instructions, reported having a migraine or being sleep-deprived to the point where they felt it affected their performance, computer error). The dashed line divides the pilot study from that reported in the main text.

Group	Prior Screening Criteria	Poor Performance	Others
Subject Pool Control	20	15	8
Subject Pool Loss	6	8	0
Pilot Old Loss	2	8	5
Young Control	11	10	2
Young Gain	2	2	4
Young Loss	12	4	1
Old Control	4	3	2
Old Gain	2	7	3
Old Loss	3	2	3
Total	62	59	28

Table II-7 Summary of ANOVA results for CTET in the pilot study.

Results for the Time factor and interactions involving it use the linear trend analysis.

Source	Sum of Squares	df	F	p	η^2_G
Age	.69	1	2.94	.089	.021
Incentive	.0019	1	.008	>.250	<.001
A x I	.716	1	3.04	.084	.021
Error	29.20	124			
Time	1.74	1	170.60**	< .001	.050
T x A	.023	1	2.25	.136	<.001
T x I	.00063	1	.062	>.250	<.001
T x A x I	.034	1	3.32	.071	<.001
Error (time)	1.26	124			
Distractor	2.12	1	146.02**	< .001	.060
D x A	.011	1	.77	>.250	<.001
D x I	.000022	1	.0015	>.250	<.001
D x A x I	.011	1	.75	>.250	<.001
Error (distractor)	1.80	124			
D x T	.0016	1	.26	>.250	<.001
D x T x A	.0012	1	.19	>.250	<.001
D x T x I	.030	1	4.80*	.030	<.001
D x T x A x I	.00028	1	.045	>.250	<.001
Error (D x T)	.78	124			

*p<.05, **p < .01

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Chapter III. Do dollars distract or demotivate? Paradoxical effects of monetary incentive on attention in younger and older adults

Abstract

It is a common assumption that offering monetary incentives can increase motivation and performance. However, our previous study in Chapter II found deleterious effects of monetary incentive in older adults. The present study aimed to replicate the previous study and further examine how incentive structure may affect attention. Younger and older adults completed a task that assesses both the initial focus of attention and the ability to sustain attention under three incentive conditions: loss, gain, or control. For the incentivized conditions, experimental runs alternated between incentivized (potential to lose money from or gain money towards a maximum performance bonus of $10) versus non-incentivized (no money lost for errors, no money gained for good performance) conditions. In the control condition, there was no performance bonus at stake. Monetary incentives reduced both young and older adults' attentional performance compared to the situation when incentive was not offered at all. When incentives were offered, performance was worse in runs when incentives were absent. Additional results from self-report measures suggest that for young adults, incentives may be distracting and lead to worse performance. In contrast, older adults were more intrinsically motivated, and the external incentive bonus appeared to decrease their motivation.

Introduction

The experiment reported in Chapter II revealed the somewhat surprising finding that loss incentives reduced the performance of older adults. At first, this seems to contradict the claims of positivity theory or at least the common heuristic interpretation that it predicts older adults will have decreased responsiveness to loss. However, we argued that the results are in good agreement with a more nuanced and mechanistic version of the positivity effect: By this interpretation, the reason older adults often seem to be less affected by negative situations or information is that they are more likely and more rapid than young adults to disengage when faced with negative situations (see review by Charles, 2010). This disengagement would be one way of explaining the increased self-reported mind-wandering in the loss-incentive condition for older adults, and would be especially detrimental to a focused-attention task, such as the Continuous Temporal Expectancy Task (CTET; O'Connell et al., 2009) in Chapter II.

The present study aims to test the replication of the impact of loss incentive on the performance of older adults, and to explore more deeply the dimensions of motivation and incentive processing that may have contributed to our results – and that may also explain the conflicting findings across other studies in this domain. Specifically, in addition to the between-subjects manipulation of incentive condition (control, loss, gain) used in the prior experiment, we also implemented a within-subjects manipulation (incentivized, non-incentivized runs) within loss and gain conditions. This allowed us to test the potential effects of the temporal dimension of incentives: Several previous studies have suggested that global, reward-context effects (is incentive present in the session or run overall?) may be different than more local, trial-specific effects (is incentive at play in this trial?), and that in particular loss incentives may have more global effects, whereas gain incentives may have more local effects (Paschke et al., 2015).

In addition, we also examined a more internal, potentially "trait" like dimension of motivation and incentive processing, the degree to which people are intrinsically versus extrinsically motivated. Our previous results of lower mind-wandering and boredom in older adults suggested that they may have more intrinsically motivated than young adults to do well on the task. We therefore measured intrinsic motivation more directly, using the Intrinsic Motivation Inventory (IMI, Ryan, 1982). Furthermore, it has been suggested that high levels of intrinsic motivation may lead to a negative response or disengagement in response to extrinsic motivation (Deci & Ryan, 2012). We therefore examined this possibility, and how it might interact with age differences and the global and local effects of different incentive valences (loss vs gain). Here I briefly review the literature on global and local as well as extrinsic and intrinsic effects of incentive processing and motivation before specifying the hypotheses of this study in further detail.

Temporal dimensions of incentive processing: Global versus local effects

Many studies have used the monetary incentive delay (MID task; Eppiner et al., 2011) task or its variants (see review by Lutz & Widmer, 2014). In these studies, participants were asked to respond to a trial after a cue indicated the amount of money that could be earned or lost for successful performance or failure. Within an incentive block, both incentive and neutral trials were presented to participants. The studies examined the local or trial specific incentive effect by comparing incentive trials to neutral trials within an incentive block, whereas a global or context-specific incentive effect was investigated by comparing neutral trials in an incentive block to neutral trials in a control block. Jimura and colleagues (2010) found incentive-context effects and that was primarily impacted by measures of proactive, goal-driven attention. Another study by

Paschke and colleagues (2015) demonstrated that gain incentives may improve performance at a local (trial specific) level, but the effects of loss incentive are more global.

In view of these intriguing results, we believe that the temporal-dynamic effects may be useful to test age-related differences in gain and loss incentives. A study by Williams and colleagues (2018) found transient effects of gain and loss incentives, as well as sustained effects of gain incentives only in congruent trials of a Franker task. They did not find behavioral evidence of incentive-based modulation in the incongruent trials, and they thus concluded that there was no behavioral effect of incentive-based modulation in attentional control. As discussed earlier, these studies manipulated monetary incentives in a trial-wise manner, which may not capture real-world experiences. We believe that using a more ecologically-valid test can provide additional insights into temporal dynamic effects of incentives.

Intrinsic versus extrinsic motivation

One of the major theories have developed from behavioral works of motivation is the self-determination theory (SDT; Deci & Ryan, 1985; 2012). Interestingly, the SDT has a multi-dimensional prediction of the local versus global effect of monetary incentives. This theory distinguishes between intrinsic and extrinsic motivation. Intrinsically motivated activities are inherently satisfying whereas extrinsically motivated activities are driven by external rewards or incentives (e.g. food or money). Since extrinsic rewards derive from external sources, these rewards may undermine one's self-determination and intrinsic motivation. This theory is often cited to explain findings of negative effects of monetary incentives and may predict a detrimental incentive effect on a global level (Deci et al. 1999, 2001).

On a local level, the SDT predicts reduced performance in non-incentivized trials due to a reduction of engagement after the withdrawal of performance-based incentives (Vansteenkiste et al., 2010). In other words, participants may engage in less of the incentivized behavior after the withdrawal of the incentive than they would have if incentive had never been offered. Importantly, the reduction in non-incentivized trials may contribute to a global undermining effect of incentives. Note that although this prediction is consistent with previous findings of local effect that performance differs between incentivized run and non-incentivized run (Paschke et al., 2015), the explanation and interpretation differ. While the local effect of incentives in studies by Paschke and colleagues (2015) has been interpreted as a beneficial effect (performance in the incentivized runs is better than performance in non-incentivized runs), the prediction by the SDT focuses on the diminished engagement after the withdrawal of the incentive (performance in the non-incentivized runs is was worse than performance in incentivized runs). The reduction of engagement has been considered a result of decreased intrinsic motivation. This reduction will be larger for larger amount of incentives or stronger extrinsic motivation (Goswami & Urminsky, 2017).

The present experiment

As noted above, the present experiment had two major goals. The first was to test the replication of our prior results, the second was to examine the contributions of other aspects of incentive and motivation processing, especially global (context) versus local (trial; or in our case, run) effects, and how these might interact with each other and contribute to age differences in performance and the response of performance to different incentive manipulations.

To replicate our previous study, we tested the following set of hypotheses:

1. Based on our previous findings, we expect to find a detrimental effect of loss on attentional performance in older adults, and no effect or a small beneficial effect on the performance of young adults.

2. We expect to replicate our previous findings in Chapter II that older adults generally report lower subjective inattention for both trait and state measures compared to young adults.
3. Again, to replicate the results in Chapter II, self-reported measures of inattention will correlate with overall CTET performance.
4. Finally, statistically controlling self-reported mind-wandering will eliminate age-related differences in CTET performance.

For temporal dynamic effects of incentive, we tested the following set of hypotheses:

1. Loss will have a greater global (context) effect than will the gain condition (Paschke, 2015), and this effect may differ between older and younger adults (testing two explanations).
2. Performance will be better in incentivized runs than in non-incentivized runs, which suggests a local effect. This effect may differ between older and younger adults (testing two explanations).
3. Compared to young adults, older adults will report higher intrinsic motivation and larger reduction of self-reported motivation in experimental condition than in the control condition.
4. As predicted by SDT, for the experimental conditions (gain and loss), the self-reported mind-wandering and boredom will decrease in incentivized runs compared to non-incentivized runs.
5. For the experimental conditions, extrinsic motivation and incentive distractibility will increase in incentivized runs compared to non-incentivized runs.

6. Differences in performance between incentivized and non-incentivized runs will positively correlate with participants' self-reported extrinsic motivation.

Methods

All methods, materials, and procedures were approved by the University of Michigan Institutional Review Board.

Participants

One hundred and seventeen young adults and 169 older adults were included in the analyses reported here (additional data collection to complete counterbalance orders is ongoing; this reports a "freeze point" to allow timely completion of the dissertation). An *a priori* power analysis conducted in G*Power 3.1.9.2 (Faul et al., 2007) indicated that a total sample size of n = 252 (42 subjects per group) would be required to detect the critical interaction at a moderate effect size.

Young adults (83 female, mean age = 20.31 years, range 18-29) were undergraduate students recruited from the University of Michigan and were paid $10 per hour for participation. Older adults (98 female, mean age = 70.69, range 60-85) were recruited from the Ann Arbor community and were paid $12 per hour for participation. Participants in each age group were randomly assigned to one of three incentive conditions: control (received no performance incentive), gain condition (start with $0, potential to earn up to $10) and loss condition (start with $10, lose 20 cents per error). Participants in the gain and loss conditions completed 10 runs of the CTET, alternating two run types between incentivized (opportunity to gain/lose money) versus non-incentivized (no money gained or lost for performance) conditions. Participants were screened to ensure physical and psychological health with no history of anxiety, depression, ADHD, or head injury, and no use of medications that affect cognition. Consistent with usual procedures in our lab, the Extended Range Vocabulary Test Version 3 (ERVT; Educational Testing Service, 1976) was used as a screen for participants who might not understand the instructions or were generally unmotivated; a minimum score of 9 out of a possible 48 was required. Data from individuals with overall very poor performance on the computer task (hit rate below 40% during the first minute of the No Distractor condition, and false alarms larger than 3 standard deviations above the mean) indicating a failure to understand or engage in the task were excluded. For older adults, a Mini Mental State Examination score (MMSE; Cockrell & Folstein, 1988) of 27 or greater was required (see Table 1 for demographic information).

Table III-1 Demographic information and self-reported measures.

Demographic information and self-reported difficulties with attentional control in everyday life (Poor Attentional Control scale; PAC; see text for details).

		Young Control (n = 39)	**Young Gain** (n = 49)	**Young Loss** (n = 29)	**Old Control** (n = 57)	**Old Gain** (n = 60)	**Old Loss** (n = 52)
Age							
	Mean	20.67	20.41	19.66	71.63	70.28	70.12
	SD	2.68	1.61	2.64	6.40	5.22	6.94
Years of Education							
	Mean	14.49	14.67	13.55	17.25	17.65	16.83
	SD	1.89	1.38	1.85	2.31	2.50	2.55
ERVT							
	Mean	21.35	19.78	16.61	31.85	30.25	29.19
	SD	6.37	6.96	6.20	7.70	8.25	7.14
PAC Mind-wandering							
	Mean	14.49	14.84	14.69	12.28	12.70	11.94

	SD	4.08	4.22	3.52	2.74	2.83	3.11
PAC Boredom							
	Mean	12.85	13.86	13.83	10.79	11.25	10.88
	SD	3.13	3.14	2.39	3.04	3.17	3.07
PAC Distractibility							
	Mean	16.31	16.80	15.48	13.33	13.47	13.00
	SD	4.66	3.81	4.49	3.20	3.40	3.20

Materials

Continuous Temporal Expectancy Task (CTET)

See Figure 1 for an illustration of the task and experimental manipulation. The task in the present study was adapted from the Continuous Temporal Expectancy Task (CTET; Berry, Li, Lin, & Lustig, 2014; O'Connell et. al., 2009). The CTET was presented on a Dell PC computer using E-prime version 2.0.8.90. During the task, a black and white grid with squares divided diagonally into halves rotated randomly at 90, 180, or 270 degrees at a standard interval of 800 ms, with occasional longer target intervals of 1070 ms. Participants were instructed to monitor the duration of rotations and press the space bar when they detected the target (longer duration rotation). Before beginning the experiment, participants were given 6 practice runs (3 targets each). To ensure that participants understood the task, the duration difference between standard trials and target trials was exaggerated during the first practice (standard: 800ms; target: 1600ms). The duration difference for the remaining 5 practice runs was identical to that used during the testing runs (800 ms standard, 1070 ms target). Participants had to achieve 100% on at least one of these 5 practice runs in order to proceed to the experiment. The experiment had 10 testing runs (4 min each) with 24 targets per run. Stimuli were presented in a pseudo-randomly intermixed fashion, such that the number of standard trials between two target trials ranged from 7 to 17 trials (with an average of 10 standard trials intervening between targets). A correct response (hit) was recorded if participants responded within 2.46s following the target offset. Responses outside this time window were coded as false alarms. At the end of each run, participants were given feedback on their performance and took a one-minute break.

For participants in the incentive conditions, the task was identical with the addition of a monetary incentive, which participants were informed about after they completed the practice. In the loss condition, participants were told that they could earn up to a $10 bonus based on task performance, and that each error (either missing a target or making a false alarm) would cost them 20 cents. Ten dollars were placed in front of the participant at the beginning of the task, and the amount was reduced as needed at the end of each run. The amount of loss was displayed at the feedback screen. The instructions for the gain procedure were the same, with the exception that participants started with $0 and reward earned during the trial was placed on the table after the feedback screen was displayed.

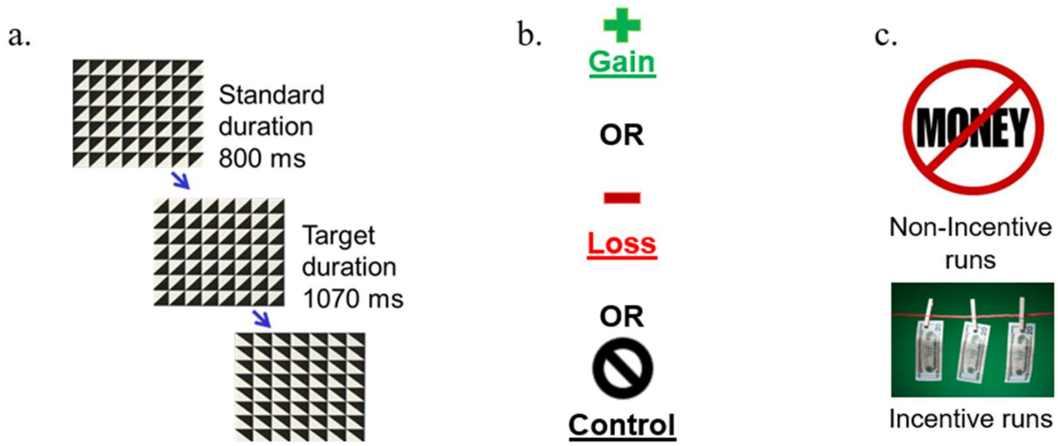

Figure III-1 Continuous temporal expectancy task (CTET) with incentives.

a. Participants viewed a grid that typically rotated every 800 ms (90, 180, or 270° rotation, randomly intermixed) and were to press the spacebar in response to the longer-duration target (1070ms). b. There were 3 incentive conditions: control, gain, and loss. Participants in the control group did not receive any performance-based bonus. In the gain condition, participants could earn up to $10 by responding correctly, while in the loss condition, they began with $10 and lost money for incorrect responses. c. In both the gain and loss condition, participants had the opportunity to win or lose money on alternating runs of the task.

Questionnaires

Poor Attentional Control (PAC) scale. Participants rated 36 statement on cognition and attention in everyday life from the Imaginal Processes Inventory (Singer & Antrobus, 1970) as to how true each statement was of them (1 = not all true of me; 5 = very true of me). As in previous papers from our group (Berry, Demeter, et al., 2014; Berry, Li, et al., 2014; Kim et al., 2017, submitted; Lin, Berry, Lustig, 2017, submitted), final analyses focused on the 15 items from the mind-wandering, boredom, and distractibility subscales, which make up the Poor Attentional Control (PAC) scale identified in a factor analysis (Huba, Singer, Aneshensel, &

Antrobus, 1982). This scale was used as the trait measure of attentional function in everyday life, and thus was administered before participants completed the computer task.

State Attention and Motivation Questionnaire (SAMQ). After each run, participants were given the SAMQ consisting of 6 questions on their level of mind-wandering, boredom, and motivation during the task based on a scale from 1 to 5. (See Supplemental Table 2.) The questions were created with similar form and content to items from PAC. As in our prior work (Berry, Demeter, et al., 2014; Berry, Li, et al., 2014; Lin et al., 2017, submitted), question "I had difficulty in keeping my attention focused on this long tedious task." was used as a state measure of mind-wandering; question "I was easily bored during this task." as boredom. The final two questions were added for the purposes of the present study, and assessed whether feedback and/or incentive might be either distracting (Q5) or motivating (Q6).

Intrinsic Motivation Inventory (IMI). After completing the CTET, IMI was administrated after the SAMQ of the last run of CTET. The IMI is a standard 22-item questionnaire assessing participants' subjective experience for a targeted activity in an experiment (Ryan, 1982). It has good internal reliability (overall coefficient alpha = .85; McAuley, Duncan, and Tammen, 1987; Markland & Hardy, 1997) and is used to assess participants' intrinsic motivation and self-regulations (e.g., Ryan, 1982). There are several different versions; we used the 22-item version. There are four subscales: interest/enjoyment, perceived choice, perceived competence, and pressure/tension (See Supplemental Table 3).

Analysis

Analyses were conducted using IBM SPSS version 24. As in prior work (Berry, Demeter, et al., 2014; Berry, Li, et al., 2014; O'Connell et al., 2009), average minute-by-minute hit rates (correct detections of target) were the primary dependent variable for the CTET.

Analyses of signal detection measures were also included in the supplemental section after the correspondent ANOVA using hit rates. Analyses below therefore report the session average for each condition.

The study was designed to test hypotheses both about between- and within-subjects effects of incentives, and whether those effects might differ according by age group and incentive type (loss vs gain). The overall study design (Age (between-subjects: young, old) X Incentive Type (between-subjects: control, loss, gain) X Run Type (within-subjects: tnon-incentivized, incentivized) X Time (within-subjects: minute 1-4), allows for a large number of potential comparisons, with Run Order (between-subjects; incentivized first, non-incentive first) potentially adding an additional dimension. We therefore report a series of analyses targeted at our hypotheses, with additional post-hoc analyses for unexpected results or exploratory questions. The omnibus ANOVA and all interactions (including those not of direct theoretical interest) are included in supplementary Table 4.1 and 4.2 for completeness.

<u>A priori hypotheses: Replication</u>

1. *Between-subjects, loss will have a detrimental effect on the focused-attention performance of older adults, with no effect or a small beneficial effect on the performance of young adults*. This hypothesis tests the overall replication of the between-subjects findings reported in Chapter II. This will be tested by examining the main effect of between-subject factor Incentive Type collapsing across different run types. Alternatively, one might ask this question by comparing the performance of the control subjects to the incentivized runs of participants in the experimental (loss and gain) groups, and so we also ran this analysis to see if it would provide converging or contradictory evidence.

2. *Older adults will have lower self-reported ratings of mind-wandering, distraction, and boredom on both trait (PAC score) and state (post-task questionnaire) measures*. Older adults typically have lower self-reported ratings of mind-wandering in everyday life (Grodsky and Giambra, 1990–1991; Giambra, 2000; Jackson and Balota, 2012; Jackson, Weinstein, and Balota, 2013) and we previously (Chapter II) showed that their ratings of boredom and distraction in everyday life, as well as their ratings on these three factors after task performance, were also lower than those of young adults. We expect to replicate these effects.
3. *State attention measures will correlate with overall CTET performance.* As reported in several studies from our lab (Berry, Demeter, et al., 2014; Berry, Li, et al., 2014; Kim et al., 2017, submitted), we generally find small to moderate effect of correlations between self-reported inattention and CTET performance.
4. *Using mind-wandering as a covariate will eliminate both age differences and incentive-group differences in CTET performance*. In the study reported in Chapter II, we found that statistically controlling mind-wandering eliminated age by incentive differences in the CTET. We expected to replicate these effects.

<u>A priori hypotheses: Temporal dynamic incentive effects</u>

1. *Between-subjects, loss will have a greater global effect ("carryover" impact even on non-incentivized runs) than will the gain condition, and this effect will differ between older and younger adults*. As described in the introduction, we compared the control subjects' performance to the non-incentivized runs of subjects in the incentivized conditions to assess the sustained effect of incentives.

2. *For the within-subjects manipulation of incentive vs non-incentive, performance will be better in the incentivized runs than the non-incentivized runs, suggesting a local effect.* The main analysis for this question is the comparison of incentivized versus incentivized runs for the gain and loss groups. As secondary hypotheses, the young adults may show stronger within-subjects effect of gains than do older adults (as older adults may be less flexible in adjusting performance in response to incentive), but the two age groups may show similar effects for the loss incentive condition, (as loss has been suggested to have stronger context effects than gain even in studies with younger adults; Paschke and colleagues (2015).
3. *Older adults will show higher intrinsic motivation compared to young adults for overall session, and compared to young adults, they will show larger reduction of self-reported motivation in experimental conditions compared to the control condition.* For intrinsic motivation, the main analysis of this question is to compare older adults' ratings on IMI to that of young adults. For the extrinsic motivation, the main analysis is to conduct a factorial age group x incentive condition ANOVA on participants' self-reported motivation.
4. *For the "state" measures of mind-wandering and boredom, the monetary incentives will decrease boredom and mind-wandering in the incentivized runs compared to non-incentivized runs*. This hypothesis will be tested by comparing the mind-wandering and boredom during the incentivized runs to the non-incentivized runs for participants in gain and loss conditions. As secondary hypotheses, young adults will show larger increases in boredom for non-incentivized runs than for incentivized runs

than will older adults (as older adults generally reported low boredom across incentive conditions described in Chapter II).

5. *For the "state" measures of motivation and distractibility, the monetary incentives will increase motivation and distractibility in incentivized run than for non-incentivized runs.* This hypothesis will be tested by comparing the motivation and distractibility during the incentivized runs to the non-incentivized runs for participants in gain and loss conditions.
6. *The performance reduction between non-incentivized runs and incentivized runs will positively correlate with participants' self-reported motivation*. The analysis of this question is the correlation between performance difference between incentivized runs and non-incentivized runs. We expected to only see this relationship in the experimental conditions but not the control condition

Results

CTET results are illustrated in Figure 2. Statistical analyses reported here focus on effects involving age and the incentive manipulation; full ANOVA results for the CTET are reported in Table 5.1 and 5.2 4.

We replicated standard effects of time-on-task declines (linear trend), $F(1, 280) = 392.10$, $p < .001$, $\eta^2 = .583$. Before going on to the hypothesis tests, we note three unexpected general findings: First, older adults had significantly better performance overall than did young adults, $F(1, 280) = 7.53$, $p < .01$, $\eta^2 = .026$. Second, the interaction between age group and time was also significant, $F(1, 280) = 7.86$, $p < .01$, $\eta^2 = .027$. A follow-up slope analysis suggested a steeper time-on-task performance decline in young adults, $t(284) = 2.76$, $p < .01$, CI = .004 - .021. This was also the case when analyzing the data only for the control condition, $F(1, 94) =$

4.66, $p < .05$, $\eta^2 = .047$, suggesting it was not driven entirely by age differences in sustaining attention in response to the incentive. Third, the interaction between incentive condition and time was significant, $F(2, 280) = 4.23$, $p < .05$, $\eta^2 = .029$, suggesting incentive conditions reduced participants' ability to sustain attention over time. Performance in the gain and loss conditions declined at similar rates, $t < 1$. In contrast, performance in the control condition declined more slowly than in the gain or loss conditions, $t(203) = 2.82$, $p < .01$, CI = .005 - .025, $t(175) = 2.43$, $p < .05$, CI = .002 - .023, respectively. To determine whether the differences in sustained attention over time might influence conclusions about the focused-attention effects of either age group or incentive group, we also analyzed only minute 1. In this case, older adults performed only marginally better than did young adults, $F(1, 280) = 3.65$, $p = .057$, $\eta^2 = .013$, and the main effect of Incentive remained significant, $F(2, 280) = 5.07$, $p < .01$, $\eta^2 = .035$. The Age x Incentive interaction did not approach significance, $F < 1$. Thus, it does not appear that the differences in the results here versus Chapter II are an artifact of time-on-task effects. As these were not expected findings and not present in our earlier datasets, they should be interpreted with caution. We report them here for completeness and in case they may influence the interpretation of our other results.

For the questionnaire measures, the PAC scale was used as a "trait" measure of attention in everyday life whereas the State Attention and Motivation Questionnaire assessed participants' subjective experience during the task (See Figure 3). See Table 1 in the main text for means and standard deviations on the PAC; See Table 2 in the Supplemental Materials for means and standard deviations on the State Attention and Motivation Questionnaire.

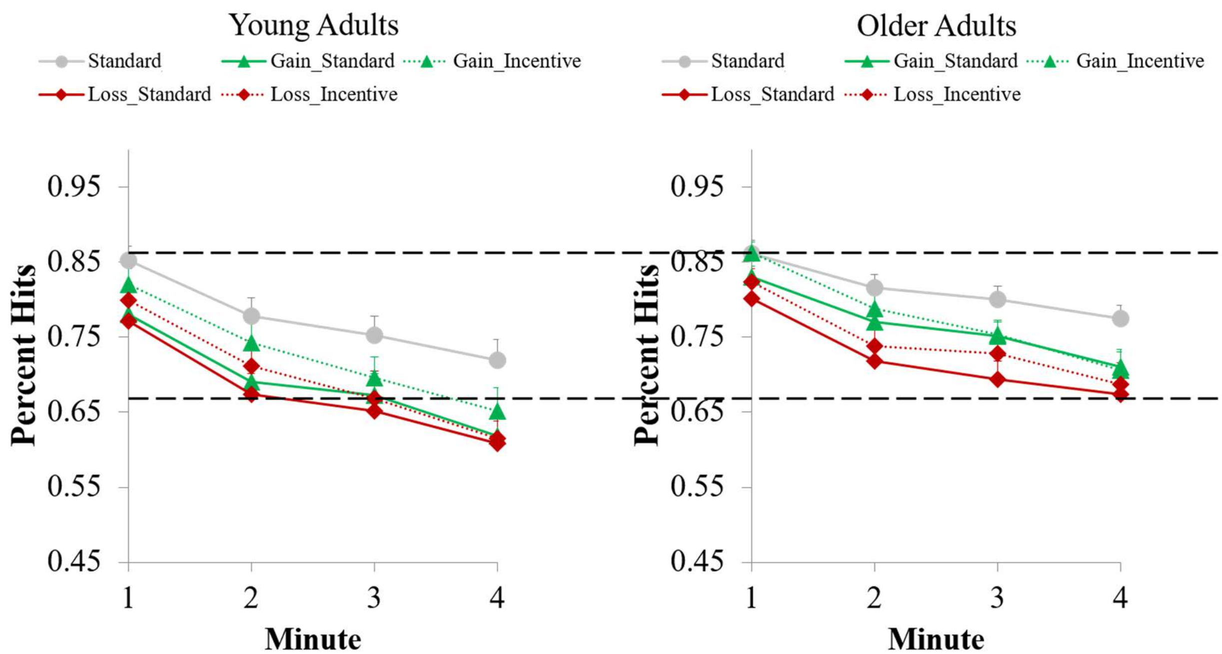

Figure III-2 Attentional performance is affected by incentive condition, run type, and age group.

Error bars represent standard errors (between-subjects; note that the run type manipulation is within-subjects). See Table 1 in Supplemental Materials for performance measures.

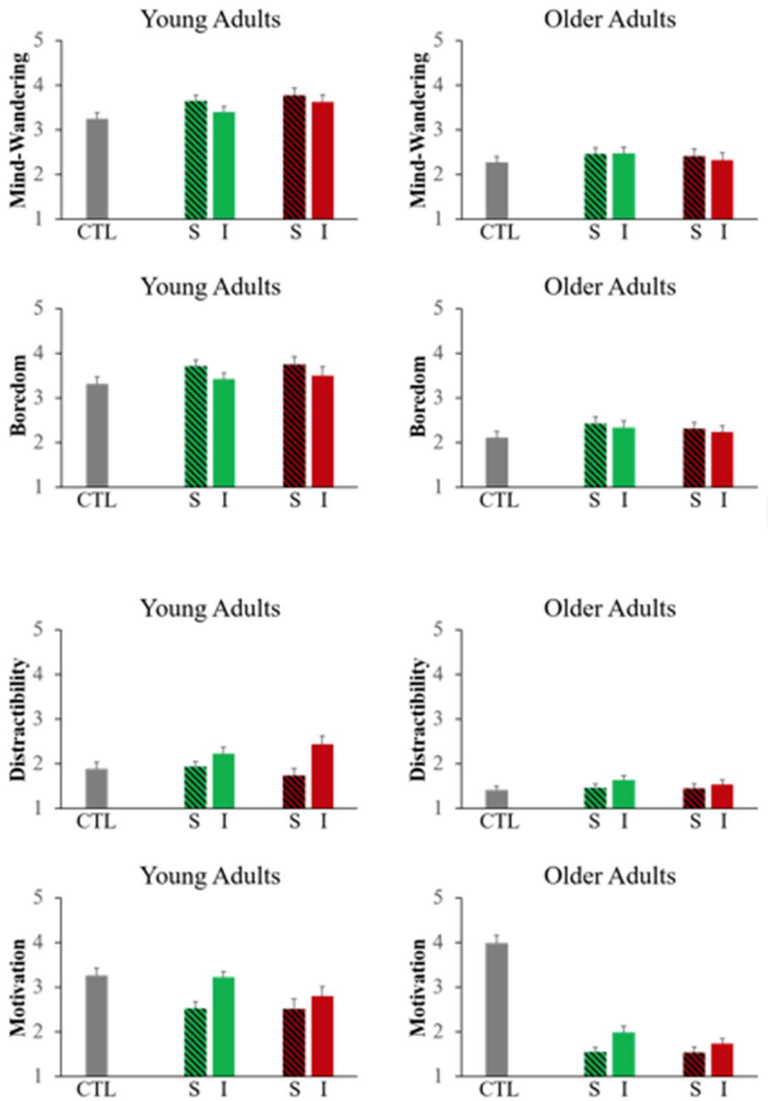

Figure III-3 Self-reported state measures are impacted by run type and age group.

See text for statistics and Table 2 in Supplemental Materials for means and standard deviations of State Attention and Motivation Questionnaire.

Replication

1. Loss incentives, as well as gain incentives, had a detrimental effect on the focused-attention performance of both older and younger adults.

We had originally hypothesized that loss incentive would have a detrimental effect on older adults' performance, while having no effect or a small beneficial effect on performance of young adults. However, young and older adults reacted similarly to the incentive manipulation. Compared to the control condition where monetary incentive was not offered at all, the incentive conditions significantly decreased performance for both young and older adults, $F(2, 280) = 7.32$, $p < .01$, $\eta^2 = .050$, with the Dunnett's t-test showing that performance in the control condition was significantly better than the gain as well as loss conditions $t(203) = 2.68$, $p <.01$, CI = .015 - .096, $t(175) = 3.72$, $p <.001$, CI = .039 - .126, respectively, while performances in gain and loss conditions were similar, $t(188) = 1.21$, $p =.229$, CI = - .017 - .071.

Although the Age x Incentive interaction was not significant, $F <1$, we continued with targeted analyses within each age group based on our a-priori hypothesis. For each age group, we conducted a follow-up ANOVA with the between-subjects factor Incentive and the within-subjects factors Run Type and Time, and used post-hoc two-sided Dunnett's t-tests to compare the control condition to each incentive condition (Details of ANOVAs, see Tables 6.1-7.2 in supplemental materials). For young adults, the main effect of incentive condition was significant, $F(2,114) = 3.19$, $p < .05$, $\eta^2 = .053$. with the Dunnett's t-test showing that performance in the gain condition was lower than the control and this effect just reached statistical significance, $t(86) = 1.96$, $p =.053$, CI = -.0001 - .135, whereas performance in the loss condition was significantly worse than performance in the control condition, $t(66) = 2.54$, $p < .05$, CI = .019 - .160. For the older adults, the main effect of incentive was also significant, $F(2,166) = 4.53$, $p < .05$, $\eta^2 = .052$, with Dunnett's t-test showing that performance in the gain condition was numerically but not statistically lower than the control condition, $t(115) = 1.72$, $p = .09$, CI = -.006 - .091, whereas performance in the loss condition was significantly worse than performance in the control condition, $t(107) = 2.83$, $p < .01$, CI = .025 - .137. The targeted analyses result for older adults were in fact consistent with our previous study.

As outlined in the analysis section, we also compared the performance of the control participants to the incentivized runs of participants in the experimental (loss and gain) groups. This analysis yielded similar results to the overall ANOVA for this hypothesis, and thus provided converging evidence. The experimental conditions significantly decreased performance for both young and older adults, $F(2, 280) = 4.74$, $p < .01$, $\eta^2 = .033$, with the Dunnett's t-test showing that performance in the control condition was significantly better than the gain as well as loss conditions $t(203) = 2.01$, $p <.01$, CI = .001 - .083, $t(175) = 3.07$, $p <.01$, CI = .025 - .114, respectively, while performances in gain and loss conditions were similar, $t(188) = 1.21$, $p =.227$, CI = - .017 - .073.

2. As predicted, older adults report lower rates of subjective inattention for both traits (PAC scores) and state (post-task questionnaire) measures.

For the PAC measures of trait inattention, consistent with the previous findings (Giambra, 1993; Jackson & Balota, 2012; Maillet & Schacter, 2016), older adults reported lower rates of mind-wandering, boredom, and distraction in everyday life than young adults did, for mind-wandering, $F(1, 280) = 32.64$, $p < .001$, $\eta^2 > .10$; boredom, $F(1, 280) = 46.60$, $p < .001$, $\eta^2 > .14$; distractibility, $F(1, 280) = 41.77$, $p < .001$, $\eta^2 > .13$.

The results for the state (task-related) attention measures were similar to those of trait measures (PAC). Older adults reported lower level of inattention compared to younger adults, for mind-wandering, $F(1, 280) = 97.86$, $p < .001$, $\eta^2 > .26$; boredom, $F(1, 280) = 100.57$, $p < .001$, $\eta^2 > .26$; distractibility, $F(1, 280) = 36.50$, $p < .001$, $\eta^2 > .12$.

3. Self-reported state inattention negatively correlated with CTET performance, while state motivation positively correlated with CTET performance.

Replicating results from previous studies (Berry et al., 2014a; Berry et al., 2014b), we found participants' self-reported mind-wandering, boredom, and distractibility negatively correlated with their CTET overall performance (See table 2). As expected, state motivation was positively correlated with CTET overall performance, suggesting that participants who reported higher level of motivation performed better in the task. For correlations between trait inattention and CTET performance, we found significant negative correlation between boredom and overall CTET performance, but not for mind-wandering. The correlation between trait distractibility and CTET performance was in the same direction as previous experiments, but did not reach significance.

Since the previous studies did not include a monetary incentive manipulation, we also examined correlations within our control groups. The findings for state inattention measures were consistent, but none of the trait correlations reached statistical significance.

These findings are partially consistent with our original hypothesis, except that trait mind-wandering did not correlate with task performance in the present study.

Table III-2 Correlations between self-reported measures and performance.

Correlations between the self-reported "state" (SAMQ scores) and "trait" (PAC scores) and attention measures and CTET performance. ** indicates p < .005

		State Attention and Motivation Questionnaire (SAMQ)				**Self-reported Everyday Attention Measure (PAC)**		
Incentive Conditions		Mind-wandering	boredom	distracti-bility	Motivation	Mind-wandering	boredom	distracti-bility

Control (n = 96)	CTET Overall	*r*	-.323	-.353	-.370	351	-.10	-.114	-.109
		p	**	**	**	**	.352	.268	.292
Gain (n = 109)	CTET Overall	*r*	-.376	-.284	-.077	.096	-147	-.261	-.264
		p	**	**	425	.320	.126	.006	.006
Loss (n = 81)	CTET Overall	*r*	-.239	-.212	.024	.103	-.018	.009	.070
		p	.032	.058	830	.359	.837	.939	.533
Overall (n = 286)	CTET Overall	*r*	-.328	-.293	-.151	.271	-.09	-.148	-.105
		p	**	**	.011	**	.128	.012	.075

4. Statistically controlling for subjective mind-wandering eliminated age effects but not incentive condition effects on performance, while statistically controlling for subjective motivation eliminated incentive condition effects but not age effects on performance

As reported from the previous section, for all incentive conditions, older adults reported less mind-wandering during the task compared to young adults, and participants' mind-wandering ratings correlated with their CTET performance, r = .33, p < .001. Therefore, we next asked whether those subjective differences in mind-wandering might account for the age effects we found on task performance. To test Hypothesis 4, we repeated the CTET ANOVA analyses, including ratings of mind-wandering during the task as a covariate (See Table 8.1 for full results). In the analysis including Age, the effect of the mind-wandering covariate was significant, $F(1, 279) = 23.23$, $p < .001$, $\eta^2 = .077$, and the previously-observed Age main effect as well as the Age X Time interaction was eliminated, both $F < 1$. These results suggest that the higher ratings in mind-wandering may account for young adults' poor performance.

To follow-up with the analysis above, we ran an additional ANCOVA, this time including ratings of motivation during the task as a covariate (See Table 9.1 for full results). As reported earlier, ratings of motivation during the task was positively correlated with participants' task performance, r = .27, p<.001. We used this analysis to explore whether those subjective differences in motivation might account for the effect of incentive we found on task performance. Results revealed a significant main effect of motivation as a covariate, $F(1, 279) = 23.27$, $p < .001$, $\eta^2 = .077$. The main effect of incentive condition, significant in the original ANOVA, was no longer significant, $F < 1$; the Incentive X Time interaction was also eliminated, $F < 1$. These results suggest that participants' self-reported motivation accounted for their performance differences across different incentive conditions.

Temporal dynamic incentive effects

1. The detrimental effect of incentives was "carried over" to non-incentivized runs, but this effect was similar for both gain and loss conditions.

We had originally hypothesized that compared to the gain condition, loss would have a greater global effect, and this effect would differ between older and younger adults. However, we found a detrimental global effect across age groups and incentive condition.

The main effect of incentive condition was significant, $F(2, 280) = 9.93$, $p < .001$, $\eta^2 = .066$. the follow-up Dunnett's t tests showed that participants in the control condition performed significantly better than participants during non-incentivized runs in the gain as well as loss conditions, $t(203) = 3.24$, $p < .001$, CI = .027 - .110; $t(175) = 4.22$, $p < .001$, CI = .050 - .149, respectively. Partially consistent with our original hypothesis that we would find a global effect, these findings suggest that the detrimental effect of incentive was "carried over" to non-incentivized runs, and thus a general context effect was evident. However, this context effect did not differ between gain and loss conditions, $t(188) = 1.16$, $p = .248$, CI = -.018 - .071. Nor did this effect differ for age group, $F < 1$.

2. When monetary incentives are offered, attentional focus is better in runs with incentives than runs without.

As predicted, we found a local effect of monetary incentive. The interaction between run type and incentive conditions was significant, $F(2, 280) = 7.68$, $p < .01$, $\eta^2 = .052$. While attentional performance was similar in alternating runs in the control conditions, $t < 1$, performance in incentivized runs was better than that of non-incentivized runs in gain and loss conditions, $t(108) = 4.10$, $p < .001$, CI = - .034 - -.012; $t(80) = 3.46$, $p < .001$, CI = - .035 - -.009, respectively. None of the other interactions involving run type reached statistical significance.

Consistent with our original hypothesis, we found that within-subjects, attentional performance was better in incentivized runs compared to non-incentivized runs. However, we did not find evidence of valence or age differences in these effects as predicted in our secondary hypothesis.

3. Compared to young adults, older adults had higher rates of intrinsic motivation, and they also showed larger reduction of self-reported motivation in experimental conditions compared to the control condition.

We predicted that older adults would show higher rates of intrinsic motivation compared to young adults. According to SDT, the highly intrinsically motivated individuals would be more negatively impacted by extrinsic motivation, and thus we also predicted that older adults would show a larger reduction of self-reported motivation in experimental conditions compared to control. As predicted, compared to young adults, older adults reported a higher level of intrinsic motivation. They reported significantly higher enjoyment, competence, and choice, and lower pressure when compared to young adults, $F(1, 280) = 83.02$, $p < .001$, $\eta^2 = .229$, $F(1, 280) = 22.04$, $p < .001$, $\eta^2 = .073$, $F(1, 280) = 14.44$, $p < .001$, $\eta^2 = .049$, $F(1, 280) = 12.10$, $p < .01$, $\eta^2 = .041$, respectively (See Table 3 in Supplemental Materials for means and standard deviations).

The main effect of Incentive Condition was significant only for competence, $F(2, 280) = 4.18$, $p < .05$, $\eta^2 = .029$, but not other dimensions, all $F < 2.15$, $p > .118$. Follow-up Dunnett's t tests showed that participants in the control condition reported significantly higher competence than participants in the gain condition, $t(203) = 2.81$, $p < .01$, CI = .178 - 1.01, The competence ratings for control participants were numerically higher but not significantly different compared to the loss condition, $t(175) = 1.64$, $p = .102$, CI = -.077 - .842. There were no effects of Age X Incentive interactions on any of the dimensions of IMI, all $F < 1.91$.

For self-reported motivation during the task, older adults also showed a larger reduction during the experimental conditions compared to the control condition relative to young adults (see Figure 3) and these effects were also confirmed quantitatively.. We conducted an Age x Incentive Condition ANOVA on participants' self-reported motivation. The age x incentive condition interaction was significant, $F(2, 280)=25.76$, $p< .001$, $\eta^2 = .155$. For each age group, we conducted a follow-up ANOVA with the between-subjects factor Incentive and the within-subject factors Run Type and Time, and used post-hoc two-sided Dunnett's t-tests to compare the control condition to each incentive condition. For young adults, the main effect of Incentive was significant, $F(2, 114)=3.532$, $p< .05$, $\eta^2 = .058$, with the Dunnett's t-test showing that performance in the gain condition was numerically but not statistically lower than the control condition ($p =.117$, CI = -.843 - .078), whereas performance in the loss condition was significantly worse than performance in the control condition ($p = .022$, CI = -1.129 - -.076). For older adults, the main effect of Incentive was significant, $F(2, 166)=97.12$, $p< .001$, $\eta^2 = .539$, with the Dunnett's t-test showing that performance in both gain and loss condition were significantly lower than the control condition ($p < .001$, CI = -2.649 - -1.814, $p<.001$, CI = -2.79 - -1.928).

Our results confirmed that older adults were more intrinsically motivated than younger adults. Compared to young adults, they showed a larger reduction of motivation during the task during the experimental conditions compared to the control condition. These results are consistent with the interpretation that extrinsic incentives are more detrimental to those who are highly intrinsically motivated.

4 . Subjective mind-wandering and boredom were reduced during non-incentivized runs compared to incentivized runs. These reductions were larger for young adults compared to older adults.

Consistent with our predictions, in both gain and loss conditions, participants reported less mind-wandering and boredom during incentivized runs compared to non-incentivized runs, for mind-wandering, $F(1, 186) = 13.28$, $p < .001$, $\eta^2 > .07$; boredom, $F(1, 186) = 31.89$, $p < .001$, $\eta^2 > .15$. Moreover, the Age group x Run Type interactions were significant across these measures such that young adults showed a larger effect of run type than that of older adults, for mind-wandering, $F(1, 186) = 6.65$, $p < .05$, $\eta^2 > .04$; boredom, $F(1, 186) = 9.55$, $p < .001$, $\eta^2 > .05$; distractibility, $F(1, 186) = 11.40$, $p < .001$, $\eta^2 > .06$. Since the incentive and non-incentivized runs were alternating, data from the control condition were analyzed in the same manner to test if there were order effects. This was not the case: In the control condition, participants reported similar levels of inattention in alternating runs. These results suggest that the absence of monetary incentives increased participants' level of mind-wandering and boredom during the task and these increases were larger for young adults than for older adults.

5. Participants reported higher levels of motivation as well as distractibility during incentivized runs than non-incentivized runs. The distractor effect was larger for younger adults than for older adults.

As predicted, participants reported higher motivation during incentivized runs compared to non-incentivized, $F(1, 188) = 49.88$, $p < .001$, $\eta^2 = .211$. Self-reported distractibility was also higher during incentivized runs compared to non-incentivized, $F(1, 188) = 22.44$, $p < .001$, $\eta^2 = .17$, suggesting that participants were more distracted during incentivized runs compared to non-incentivized runs. For self-reported distractibility, the interaction between Age and Run Type was significant, $F(1,186) = 11.40$, $p <.01$, $\eta^2 = 058$, suggesting that young adults found extrinsic incentive more distracting compared to older adults.

As an exploratory analysis, we also tested the relationship between state motivation and distractibility as a function of incentive condition. While for the control condition, distractibility negatively correlated with motivation, $r = -.560$, $p <.001$, distractibility was positively correlated with motivation in the gain and loss conditions, $r = .543$, $p <.001$, $r = .704$, $p <.001$. In the control condition, participants who reported feedback as more distracting reported lower motivation. For the gain and loss conditions, participants who found motivation more distracting also reported higher rates of motivation. These results together with the CTET results suggest that the monetary incentives may be distracting and may contribute to reduced performance during the experimental conditions.

6. For gain and loss conditions, participants' extrinsic motivation positively correlated with performance reduction between incentive vs non-incentivized runs.

The results are consistent with our hypothesis. For the gain condition, participants' state motivation was positively correlated with the performance difference between incentivized runs and non-incentivized runs, $r = .243$, $p < .05$. The same relationship was found in the loss condition, $r = .285$, $p < .05$. As predicted, this relationship was not significant in the control condition $r = -.008$, $p = .937$. Note that there were no incentivized runs in the control condition. The performance difference in the control group was a "dummy comparison" and the score was calculated by the average difference between alternating runs.

Discussion

A central aim of the present study was to replicate findings from the previous study in Chapter II. As predicted, older adults showed a decrease in performance in the loss condition compared to the control condition. We also replicated the common findings that older adults report lower rates of mind-wandering, boredom, and distractibility both in daily life and during the task compared to young adults (in addition to Chapter II, see Giambra, 1993; Jackson & Balota, 2012; Maillet & Schacter, 2016). Furthermore, we generally replicated the relationships between CTET performance and self-reported measures that have now been found in several different studies in our laboratory (Berry, Demeter, et al., 2014; Berry, Li, et al., 2014; Kim et al., 2017).

There were also several unexpected findings, including some that contradicted our initial hypotheses and stand in contrast to the findings that Chapter II reported. Of particular interest is that, both younger and older adults in the incentive groups showed worse performance than did those in the control condition. Moreover, older adults generally outperformed young adults, and young adults also were more sensitive to time-on-task decline. Of course, one possible explanation is that our earlier results of age-related differences were not reliable. However, based on targeted analyses, another possibility is that the major conceptual conclusions in Chapter II still have merit, but that the within-subjects manipulation alters how participants, especially young adults, respond to the incentive, and this also has carryover effects to the non-incentivized runs.

Although the Age X Incentive interaction did not reach statistical significance, targeted analyses within each age group revealed that for the older adults, participants in the control group performed better than participants in the loss group did on either incentivized or non-incentivized runs. Meanwhile, the results for the control group and the gain-incentive group did not differ regardless of the run type (incentivized versus non-incentivized) that was used for comparison. These results resemble those of Chapter 2, where the gain condition also demonstrated an intermediate effect between the control and loss condition for the older adults.

The unexpected result for Incentive condition was the main effect of the Incentive condition for young adults. In contrast to the results for older adults, for young adults the valence (gain versus loss) seemed to have less of an impact. Instead, the presence or absence of within-subjects incentive may have played a larger role. Specifically, for young adults in both the gain and loss conditions, performance in the incentivized runs did not significantly differ from that of participants in the control condition, whereas performance in the non-incentivized runs (again, regardless of valence) was significantly worse than that of the control participants. One potential interpretation of this pattern is that young adults may experience a decrease in motivation and attention in non-incentivized runs when they are tested in the context of other incentivized runs.

With regard to the mechanisms for observed performance effects, the questionnaire data provide suggestions that are interesting, though admittedly tentative. First, boredom and distractibility tended to greater among the incentivized groups. These results were consistent with findings from previous studies on extrinsic and intrinsic motivation in which participants engaged less in a task after an incentive ended (Deci & Ryan, 1985). This reduced engagement was thought to result from a reduction in intrinsic motivation (Deci, Koestner & Ryan, 1999, 2001; Lepper, Henderlong, & Gingras, 1999). In our study, incentivized and non-incentivized runs were conducted in an alternating order. The predictable timing of incentives may contribute to the increased boredom during non-incentivized runs, as participants already knew those runs were non-incentivized. Second, the older adults in the incentivized groups generally reported less motivation compared to those in the control group. In contrast, for young adults, the questionnaire results suggest that they may have been distracted by thoughts about the incentive (or lack thereof on non-incentivized runs).

Rather than viewing the above explanations as definitive conclusion, they should be considered tentative hypotheses that warrant more direct testing in future studies. Admittedly, in some ways, the results of the present study raise more questions than they answer. However, they highlight several potential factors that may not receive sufficient attention in the current literature about the effects of incentives on attention and cognitive control, or about age-related differences in that regard. Most importantly, they indicate that although incentives have beneficial effects on performance *within* subjects, they may have quite different, and perhaps even detrimental, effects *between* subjects. Between-subjects, incentives may actually decrease motivation, especially for older adults, and increase distractibility and mind-wandering about the incentive itself, with this latter effect potentially playing a larger role for young adults. When varied within-subjects, the presence of an incentive on some runs may actually decrease motivation on non-incentivized runs, rather than “increasing” motivation per se – an interpretation that drastically differs from the dominant interpretation in the literature. Understanding the mechanisms that underlie these different effects will require further testing and studies that are designed specifically to test the hypotheses that have emerged from the current results. Nevertheless, documenting this discrepancy may already be a valuable contribution and caveat to the literature on the effects of incentive on motivation, attention, and cognitive control.

Appendix B.

Additional results from main-text experiment

Table III-3 CTET performance for each group.

Means and confidence intervals for attentional performance in each group (hits, false alarm, and d')

	Time							
	Minute 1		Minute 2		Minute 3		Minute 4	
Performance	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Young control no distractor hits (%)	82.08	[77.03, 87.12]	77.79	[71.77, 83.81]	75.67	[69.35, 81.99]	72.08	[64.72, 79.44]
Young control distractor hits (%)	75.68	[70.53, 80.82]	72.70	[66.52, 78.89]	66.25	[59.82, 72.69]	63.84	[57.50, 70.17]
Young gain no distractor hits (%)	87.82	[83.39, 92.26]	85.19	[80.33, 90.05]	79.59	[72.94, 86.25]	77.14	[71.08, 83.20]
Young gain distractor hits (%)	81.53	[76.31, 86.74]	77.25	[71.18, 83.32]	74.80	[66.89, 82.71]	68.01	[60.62, 75.40]
Young loss no distractor hits (%)	86.41	[82.04, 90.78]	79.90	[74.44, 85.36]	80.43	[75.86, 84.99]	74.11	[67.67, 80.55]
Young loss distractor hits (%)	79.39	[73.15, 85.62]	77.73	[71.63, 83.83]	70.55	[63.27, 77.83]	68.26	[61.12, 75.40]
Old control no distractor hits (%)	84.56	[80.78, 88.33]	80.16	[74.54, 85.79]	75.29	[69.63, 80.94]	74.63	[68.32, 80.93]
Old control distractor hits (%)	70.29	[64.16, 76.42]	73.37	[67.23, 79.52]	70.29	[63.67, 76.91]	64.10	[56.19, 72.01]
Old gain no distractor hits (%)	79.64	[74.09, 85.19]	78.56	[72.81, 84.31]	74.40	[68.40, 80.40]	68.88	[62.31, 75.46]

Old gain distractor hits (%)	72.87	[66.88, 78.87]	68.35	[61.42, 75.28]	64.22	[57.52, 70.92]	61.11	[54.17, 68.06]
Old loss no distractor hits (%)	74.75	[68.82, 80.67]	72.84	[66.09, 79.59]	69.19	[62.82, 75.55]	63.01	[55.42, 70.60]
Old loss distractor hits (%)	64.01	[56.37, 71.65]	61.77	[54.51, 69.04]	58.81	[49.94, 67.69]	52.07	[44.19, 59.94]
Young control no distractor FA (%)	1.07	[0.09, 2.04]	1.38	[0.20, 2.57]	1.16	[0.18, 2.14]	1.32	[0.24, 2.40]
Young control distractor FA (%)	1.28	[0.22, 2.34]	1.66	[0.30, 3.02]	1.63	[0.39, 2.86]	1.60	[0.37, 2.83]
Young gain no distractor FA (%)	0.33	[0.23, 0.43]	0.37	[0.21, 0.53]	0.32	[0.19, 0.45]	0.35	[0.28, 0.42]
Young gain distractor FA (%)	0.34	[0.23, 0.44]	0.36	[0.25, 0.46]	0.33	[0.22, 0.44]	0.45	[0.31, 0.60]
Young loss no distractor FA (%)	0.43	[0.21, 0.64]	0.33	[0.14, 0.52]	0.28	[0.19, 0.38]	0.49	[0.32, 0.67]
Young loss distractor FA (%)	0.30	[0.22, 0.38]	0.41	[0.22, 0.59]	0.35	[0.23, 0.46]	0.51	[0.35, 0.67]
Old control no distractor FA (%)	1.81	[0.82, 2.80]	1.47	[0.64, 2.30]	0.97	[0.47, 1.47]	1.30	[0.66, 1.94]
Old control distractor FA (%)	2.35	[1.12, 3.57]	1.78	[0.74, 2.83]	1.50	[0.69, 2.30]	1.39	[0.41, 2.36]
Old gain no distractor FA (%)	1.36	[0.73, 1.99]	1.15	[0.51, 1.79]	1.02	[0.48, 1.55]	1.11	[0.66, 1.57]
Old gain distractor FA (%)	1.34	[0.81, 1.86]	1.38	[0.78, 1.98]	0.90	[0.56, 1.24]	1.03	[0.52, 1.55]
Old loss no distractor FA (%)	1.52	[0.49, 2.54]	1.25	[0.40, 2.11]	1.12	[0.32, 1.92]	1.07	[0.42, 1.73]
Old loss distractor FA (%)	1.44	[0.42, 2.46]	1.58	[0.60, 2.55]	1.02	[0.40, 1.63]	1.28	[0.34, 2.21]

Young control no distractor d'	3.68	[3.40, 3.97]	3.44	[3.11, 3.76]	3.39	[3.11, 3.67]	3.22	[2.91, 3.53]
Young control distractor d'	3.37	[3.06, 3.68]	3.17	[2.87, 3.47]	2.91	[2.66, 3.17]	2.85	[2.56, 3.13]
Young gain no distractor d'	4.13	[3.89, 4.38]	4.00	[3.75, 4.25]	3.81	[3.52, 4.10]	3.62	[3.38, 3.86]
Young gain distractor d'	3.83	[3.59, 4.08]	3.65	[3.38, 3.93]	3.63	[3.32, 3.93]	3.29	[2.98, 3.60]
Young loss no distractor d'	4.01	[3.75, 4.28]	3.79	[3.54, 4.04]	3.81	[3.58, 4.04]	3.45	[3.16, 3.74]
Young loss distractor d'	3.82	[3.53, 4.11]	3.69	[3.40, 3.98]	3.47	[3.17, 3.76]	3.23	[2.98, 3.48]
Old control no distractor d'	3.54	[3.26, 3.82]	3.45	[3.13, 3.77]	3.32	[3.08, 3.57]	3.26	[2.95, 3.57]
Old control distractor d'	2.87	[2.56, 3.18]	3.08	[2.79, 3.37]	3.03	[2.75, 3.32]	2.89	[2.59, 3.19]
Old gain no distractor d'	3.43	[3.12, 3.74]	3.42	[3.13, 3.72]	3.28	[3.02, 3.55]	3.06	[2.74, 3.37]
Old gain distractor d'	3.10	[2.81, 3.39]	2.95	[2.66, 3.25]	2.94	[2.69, 3.20]	2.83	[2.56, 3.09]
Old loss no distractor d'	3.24	[2.93, 3.54]	3.27	[2.94, 3.60]	3.14	[2.85, 3.44]	2.87	[2.60, 3.15]
Old loss distractor d'	2.88	[2.58, 3.18]	2.76	[2.47, 3.05]	2.84	[2.51, 3.18]	2.55	[2.26, 2.84]
Young control no distractor bias	0.91	[0.85, 0.96]	0.90	[0.85, 0.94]	0.92	[0.88, 0.96]	0.91	[0.87, 0.96]
Young control distractor bias	0.92	[0.88, 0.96]	0.91	[0.86, 0.96]	0.93	[0.88, 0.97]	0.94	[0.90, 0.98]
Young gain no distractor bias	0.90	[0.87, 0.94]	0.89	[0.82, 0.96]	0.94	[0.92, 0.96]	0.94	[0.90, 0.97]

Young gain distractor bias	0.93	[0.90, 0.96]	0.95	[0.93, 0.97]	0.95	[0.92, 0.97]	0.96	[0.93, 0.98]
Young loss no distractor bias	0.91	[0.88, 0.94]	0.95	[0.93, 0.97]	0.95	[0.93, 0.97]	0.95	[0.93, 0.97]
Young loss distractor bias	0.93	[0.91, 0.96]	0.93	[0.90, 0.97]	0.96	[0.94, 0.98]	0.95	[0.93, 0.97]
Old control no distractor bias	0.81	[0.73, 0.88]	0.88	[0.83, 0.93]	0.92	[0.88, 0.96]	0.90	[0.85, 0.94]
Old control distractor bias	0.89	[0.85, 0.93]	0.89	[0.84, 0.93]	0.92	[0.88, 0.95]	0.95	[0.93, 0.97]
Old gain no distractor bias	0.86	[0.77, 0.95]	0.90	[0.85, 0.95]	0.92	[0.88, 0.97]	0.94	[0.92, 0.97]
Old gain distractor bias	0.91	[0.88,0.94]	0.93	[0.89, 0.96]	0.95	[0.92, 0.98]	0.96	[0.95, 0.98]
Old loss no distractor bias	0.90	[0.85, 0.95]	0.91	[0.86, 0.96]	0.95	[0.93, 0.97]	0.95	[0.93, 0.97]
Old loss distractor bias	0.94	[0.91, 0.97]	0.94	[0.92, 0.97]	0.96	[0.95, 0.98]	0.97	[0.95, 0.98]

Table III-4 Means and standard deviations for state subjective attention and motivation.

	Young Control (n = 49)		**Young Gain** (n = 49)		**Young Loss** (n = 29)		**Old Control** (n = 57)		**Old Gain** (n = 60)		**Old Loss** (n = 52)	
	I	**Non-I**	**I**	**Non-I**	**I**	**Non-I**	**I**	**Non-I**	**I**	**Non-I**	**I**	**Non-I**
1. At times of this task, it was hard for me to keep my mind from wandering.												
mean	3.19	3.14	3.22	3.43	3.49	3.73	2.26	2.38	2.43	2.42	2.22	2.24
SD	*1.02*	*1.00*	*0.94*	*0.88*	*0.89*	*0.75*	*0.95*	*0.99*	*1.01*	*1.01*	*0.87*	*0.87*
2. (*reverse scored*) During the task, my thoughts seldom drifted from the subject before me.												
mean	3.28	3.35	3.57	3.80	3.37	3.68	3.04	3.04	2.99	2.91	3.01	3.06
SD	*1.05*	*0.93*	*0.78*	*0.72*	*0.88*	*0.74*	*1.12*	*1.05*	*0.97*	*0.97*	*0.96*	*0.90*
3. I was easily bored during this task.												
mean	3.27	3.35	3.42	3.71	3.50	3.74	2.12	2.11	2.33	2.42	2.24	2.30
SD	*1.04*	*1.00*	*0.98*	*0.92*	*1.07*	*0.99*	*1.07*	*1.05*	*1.14*	*1.15*	*0.98*	*0.99*
4. I had difficulty in keeping my attention focused on this long, tedious task.												
mean	3.21	3.28	3.39	3.65	3.62	3.78	2.22	2.31	2.48	2.46	2.32	2.41
SD	*0.91*	*0.93*	*0.90*	*0.80*	*0.86*	*0.86*	*0.94*	*1.04*	*1.04*	*1.09*	*0.91*	*0.98*
5. I found the feedback to be distracting. (Control) **I found the possibility of wining/losing money to be distracting. (I)** **I found that thinking that I would not win/lose money on this run to be distracting. (Non-I)**												
mean	1.88	1.90	2.22	1.93	2.43	1.73	1.39	1.44	1.63	1.46	1.53	1.45
SD	*0.87*	*0.93*	*0.98*	*0.82*	*1.02*	*0.89*	*0.57*	*0.70*	*0.82*	*0.65*	*0.66*	*0.67*
6. I found the feedback to be motivating. (Control) **I found the possibility of winning/losing money to be motivating. (I)** **I found thinking I would not win/lose money on this run to be demotivating. (Non-I)**												

mean	3.28	3.23	3.22	2.52	2.80	2.50	3.93	4.06	1.98	1.54	1.73	1.53
SD	*0.97*	*1.08*	*0.92*	*1.01*	*1.11*	*1.22*	*1.26*	*1.22*	*1.13*	*0.79*	*0.95*	*0.81*

Table III-5 Means and standard deviations for Intrinsic Motivation Inventory.

IMI items		Young Adults			Older Adults		
		Control	Gain	Loss	Control	Gain	Loss
Enjoyment	Mean	2.35	2.48	2.34	4.08	3.97	3.80
	SD	*1.09*	*1.35*	*1.18*	*1.63*	*1.48*	*1.41*
Competence	Mean	4.03	3.23	3.26	4.56	4.18	4.36
	SD	*1.34*	*1.84*	*1.72*	*1.41*	*1.22*	*1.57*
Choice	Mean	5.41	5.46	5.37	6.07	6.05	5.65
	SD	*.763*	*1.06*	*1.26*	*.884*	*1.12*	*1.38*
Pressure/Tension	Mean	3.04	3.51	3.57	2.65	2.78	2.95
	SD	*1.28*	*1.47*	*1.64*	*1.40*	*1.25*	*1.21*

Table III-6 Summary of the Age X Incentive Type X Run Type X Time X Run Order ANOVA on hit rates results.

Summary of the Age (between-subjects: young, old) X Incentive Type (between-subjects: loss, gain) X Run Type (within-subjects: non-incentivized, incentivized) X Time (within-subjects: minute 1-4) X Run Order (between-subjects; incentivized first, non-incentive first) ANOVA on hit rates results for CTET. Results for the Time factor and interactions involving it use the linear trend analysis.

Source	Sum of Squares	df	F	p	η_p^2
Age	.991	1	5.58*	.019	.030
Incentive	.308	1	1.73	.19	.009
Run Order	.011	1	.060	.806	.000
A x I	.021	1	.121	.729	.001
A x RO	.155	1	.871	.352	.005
I x RO	.217	1	1.22	.270	.007
A x I x RO	.415	1	2.34	.128	.013
Error	32.33	182			
Time	4.12	1	284.45**	< .001	.610
T x A	.057	1	3.92*	.049	.021
T x I	.000	1	.004	.947	.000
T x RO	.030	1	2.09	.150	.011
T x A x I	.003	1	.189	.664	.001
T x A x RO	.008	1	.546	.461	.003
T x I x RO	.001	1	.047	.828	.000
T x A x I x RO	.012	1	.832	.363	.005
Error (time)	2.64	182			
Run Type	.195	1	29.86**	<.001	.141
R x A	.013	1	2.05	.154	.011
R x I	.000	1	.068	.795	.000
R x RO	.008	1	1.27	.262	.007
R x A x I	.015	1	2.32	.129	.013
R x A x RO	.001	1	.149	.700	.001
R x I x RO	.005	1	.726	.395	.004
R x A x I x RO	.000	1	.060	.807	.000
Error (Run Type)	1.19	182			
R x T	.019	1	2.96	.087	.016
R x T x A	.000	1	.001	.980	.000
R x T x I	.001	1	.221	.638	.001
R x T x RO	.003	1	.471	.494	.003
R x T x A x I	.006	1	.957	.329	.005

R x T x A x RO	.001	1	.222	.638	.001
R x T x I x RO	.000	1	.000	.987	.000
R x T x A x I x RO	.005	1	.803	.371	.004
Error (R x T)	1.20	182			

*p<.05, **p < .01

Table III-7 Summary of the Age X Incentive Type X Run Type X Time X Run Order ANOVA on d' results.

Summary of the Age (between-subjects: young, old) X Incentive Type (between-subjects: loss, gain) X Run Type (within-subjects: non-incentivized, incentivized) X Time (within-subjects: minute 1-4) X Run Order (between-subjects; incentivized first, non-incentive first) ANOVA on d' results for CTET. Results for the Time factor and interactions involving it use the linear trend analysis.

Source	Sum of Squares	df	F	p	η_p^2
Age	1.63	1	.409	.523	.002
Incentive	14.03	1	3.52	.062	.019
Run Order	2.72	1	.569	.451	.003
A x I	1.58	1	.396	.530	.002
A x RO	4.07	1	1.02	.328	.005
I x RO	3.85	1	.964	.328	.005
A x I x RO	.881	1	.221	.639	.001
Error	726.00	182			
Time	45.89	1	200.65**	< .001	.524
T x A	1.33	1	5.82*	.017	.031
T x I	.000	1	.000	.999	.000
T x RO	.336	1	1.47	.227	.008
T x A x I	.116	1	.507	.477	.003
T x A x RO	.002	1	.007	.935	.000
T x I x RO	.496	1	2.17	.143	.012
T x A x I x RO	.382	1	1.67	.198	.009
Error (time)	41.62	182			

Run Type	4.53	1	26.02**	<.001	.125
R x A	.413	1	2.37	.125	.013
R x I	.007	1	.041	.840	.000
R x RO	4.28	1	24.60**	<.001	.119
R x A x I	.097	1	.560	.455	.003
R x A x RO	.046	1	.267	.606	.001
R x I x RO	.043	1	.248	.619	.001
R x A x I x RO	.050	1	.288	.592	.002
Error (Run Type)	31.68	182			
R x T	.130	1	.873	.351	.005
R x T x A	.003	1	.021	.884	.000
R x T x I	.198	1	1.33	.251	.007
R x T x RO	.067	1	.448	.504	.002
R x T x A x I	.063	1	.424	.516	.002
R x T x A x RO	.131	1	.879	.350	.005
R x T x I x RO	.006	1	.041	.840	.000
R x T x A x I x RO	.037	1	.246	.620	.001
Error (R x T)	27.11	182			

*p<.05, **p < .01

Table III-8 Summary of the Age X Incentive Type X Run Type X Time ANOVA on hit rates results.

Summary of the Age (between-subjects: young, old) X Incentive Type (between-subjects: loss, gain) X Run Type (within-subjects: non-incentivized, incentivized) X Time (within-subjects: minute 1-4) ANOVA on hit rates results for CTET (Hypothesis 1 for Replication). Results for the Time factor and interactions involving it use the linear trend analysis.

Source	Sum of Squares	df	F	p	η_p^2

Age	1.27	1	7.53**	.006	.026
Incentive	2.47	2	7.32**	.001	.050
A x I	.065	2	.194	.824	.001
Error	47.19	280			
Time	5.19	1	392.10**	< .001	.583
T x A	.104	1	7.86**	.005	.027
T x I	.112	2	4.23*	.016	.029
T x A x I	.006	2	.230	.794	.002
Error (time)	3.71	280			
Run Type	.104	1	15.65**	< .001	.053
R x A	.002	1	.325	.569	.001
R x I	.102	2	7.68**	<.001	.052
R x A x I	.035	2	2.65	.072	.019
Error (Run Type)	1.86	280			
R x T	.011	1	1.87	.173	.007
R x T x A	.000	1	.002	.962	.000
R x T x I	.014	2	1.18	.309	.008
R x T x A x I	.006	2	.507	.603	.004
Error (R x T)	1.62	280			

*p<.05, **p < .01

Table III-9 Summary of the Age X Incentive Type X Run Type X Time ANOVA on d' results.

Summary of the Age (between-subjects: young, old) X Incentive Type (between-subjects: loss, gain) X Run Type (within-subjects: non-incentivized, incentivized) X Time (within-subjects: minute 1-4) ANOVA on d’ results for CTET (Hypothesis 1 for Replication). Results for the Time factor and interactions involving it use the linear trend analysis.

Source	Sum of Squares	df	F	p	η_p^2
Age	2.60	1	.667	.415	.002
Incentive	56.49	2	7.25**	.001	.049

A x I	1.414	2	.182	.834	.001
Error	1090.62	280			
Time	63.63	1	268.21**	< .001	.489
T x A	1.81	1	7.64**	.006	.027
T x I	.356	2	.749	.474	.005
T x A x I	.133	2	.281	.755	.002
Error (time)	66.43	280			
Run Type	1.052	1	5.71*	.018	.020
R x A	.399	1	2.17	.142	.008
R x I	5.22	2	14.18**	<.001	.092
R x A x I	.120	2	.325	.723	.009
Error (Run Type)	51.59	280			
R x T	.114	1	.812	.368	.003
R x T x A	.000	1	.000	.994	.000
R x T x I	.234	2	.832	.436	.006
R x T x A x I	.074	2	.262	.770	.002
Error (R x T)	39.44	280			

*p<.05, **p < .01

Table III-10 Summary of targeted analysis for young adults (hit rates).

Incentive Type (between-subjects: loss, gain) X X Run Type (within-subjects; incentivized, non-incentive) X Time (within-subjects: minute 1-4) ANOVA on <u>hit rates</u> results for CTET (Hypothesis 1 for Replication). Results for the Time factor and interactions involving it use the linear trend analysis.

Source	Sum of Squares	df	F	p	η_p^2
Incentive	1.22	2	3.19*	.045	.053
Error	21.83	114			
T	2.81	1	247.25**	<.001	.684
T x I	.035	2	1.53	.221	.026

Error (time)	1.30	114			
Run Type	.057	1	6.95*	.01	.057
R x I	.102	2	6.24	.003	.099
Error (Run Type)	.930	114			
R x T	.004	1	.710	.401	.006
R x T x I	.005	2	.426	.654	.007
Error (R x T)	.671	114			

*p<.05, **p < .01

Table III-11 Summary of targeted analysis for young adults (d').

Incentive Type (between-subjects: loss, gain) X X Run Type (within-subjects; incentivized, non-incentive) X Time (within-subjects: minute 1-4) ANOVA on d' results for CTET (Hypothesis 1 for Replication). Results for the Time factor and interactions involving it use the linear trend analysis.

Source	Sum of Squares	df	F	p	η_p^2
Incentive	26.75	2	3.853*	.024	.063
Error	395.732	114			
T	36.15	1	185.52**	<.001	.619
T x I	.211	2	.543	.583	.009
Error (time)	22.21	114			
Run Type	1.14	1	5.84*	.017	.049
R x I	2.76	2	7.05**	.001	.110
Error (Run Type)	22.315	114			
R x T	.048	1	.361	.549	.003
R x T x I	.019	2	.073	.930	.001
Error (R x T)	15.28	114			

*p<.05, **p < .01

Table III-12 Summary of targeted analysis for older adults (hit rates).

Incentive Type (between-subjects: loss, gain) X X Run Type (within-subjects; incentivized, non-incentive) X Time (within-subjects: minute 1-4) ANOVA on hit rates results for CTET (Hypothesis 1 for Replication). Results for the Time factor and interactions involving it use the linear trend analysis.

Source	Sum of Squares	df	F	p	η_p^2
Incentive	1.39	2	4.53*	.012	.052
Error	25.37	166			
T	2.40	1	165.14**	<.001	.499
T x I	.092	2	3.16	.045	.037
Error (time)	2.41	166			
Run Type	.048	1	8.51**	.004	.049
R x I	.026	2	2.32	.102	.027
Error (Run Type)	.932	166			
R x T	.007	1	1.27	.261	.008
R x T x I	.016	2	1.37	.256	.016
Error (R x T)	.944	166			

*p<.05, **p < .01

Table III-13 Summary of targeted analysis for older adults (d').

Summary of targeted analysis for older adults, Incentive Type (between-subjects: loss, gain) X X Run Type (within-subjects; incentivized, non-incentive) X Time (within-subjects: minute 1-4) ANOVA on d' results for CTET (Hypothesis 1 for Replication). Results for the Time factor and interactions involving it use the linear trend analysis.

Source	Sum of Squares	df	F	p	η_p^2
Incentive	31.84	2	3.803*	.024	.044
Error	694.89	166			

T	27.56	1	103.45**	<.001	.384
T x I	.266	2	.499	.608	.006
Error (time)	44.21	166			
Run Type	.097	1	.552	.459	.003
R x I	2.64	2	7.48**	.001	.083
Error (Run Type)	29.273	166			
R x T	.070	1	.484	.487	.003
R x T x I	.342	2	1.17	.312	.014
Error (R x T)	24.163	166			

*p<.05, **p < .01

Table III-14 Summary of ANCOVA results (hit rates).

Summary of Age Group (between-subjects: young, old) X Incentive Type (between-subjects: loss, gain) X Run Type (within-subjects; incentivized, non-incentive) X Time (within-subjects: minute 1-4) ANOVA on hit rates with Mind-Wandering as covariate results for CTET (Hypothesis 4 for Replication). Results for the Time factor and interactions involving it use the linear trend analysis.

Source	Sum of Squares	df	F	p	η_p^2
Mind-wandering	3.63	1	23.23**	<.001	.077
Age	.000	1	.000	.999	.000
Incentive	1.75	2	5.61**	.004	.039
A x I	.085	2	.273	.761	.002
Error	43.56	279			
Time	.112	1	8.80**	.003	.031
T x MW	.150	1	11.73**	.001	.040
T x A	.007	1	.513	.474	.002
T x I	.080	2	3.14*	.045	.022
T x A x I	.006	2	.240	.787	.002
Error (time)	3.56	279			

Run Type	.001	1	.127	.722	.000
R x MW	.005	1	.825	.364	.003
R x A	.000	1	.001	.977	.000
R x I	.095	2	7.12**	.001	.049
R x A x I	.035	2	2.66	.072	.019
Error (Run Type)	1.86	279			
R x T	.000	1	.034	.854	.000
R x T x MW	.002	1	.405	.525	.001
R x T x A	.001	1	.133	.716	.000
R x T x I	.012	2	1.06	.350	.008
R x T x A x I	.005	2	.469	.626	.003
Error (R x T)	1.61	279			

*p<.05, **p < .01

Table III-15 Summary of ANCOVA results (d').

Summary of Age Group (between-subjects: young, old) X Incentive Type (between-subjects: loss, gain) X Run Type (within-subjects; incentivized, non-incentive) X Time (within-subjects: minute 1-4) ANOVA on d’ with Mind-Wandering as covariate results for CTET (Hypothesis 4 for Replication). Results for the Time factor and interactions involving it use the linear trend analysis.

Source	Sum of Squares	df	F	p	η_p^2
Mind-wandering	33.49	1	8.84**	.003	.031
Age	2.43	1	.640	.424	.002
Incentive	46.11	2	6.08**	.003	.042
A x I	0.803	2	.106	.899	.001
Error	1057.13	279			
Time	1.12	1	4.88*	.028	.017
T x MW	2.17	1	9.41**	.002	.033
T x A	.168	1	.728	.394	.003

T x I	.163	2	.354	.702	.003
T x A x I	.078	2	.170	.844	.001
Error (time)	64.26	279			
Run Type	.001	1	.008	.931	.000
R x MW	.138	1	.750	.387	.003
R x A	.126	1	.682	.410	.002
R x I	4.93	2	13.35**	<.001	.087
R x A x I	.122	2	.330	.719	.002
Error (Run Type)	51.45	279			
R x T	.091	1	.646	.422	.002
R x T x MW	.182	1	1.29	.256	.005
R x T x A	.046	1	.327	.568	.001
R x T x I	.219	2	.779	.460	.006
R x T x A x I	.068	2	.240	.787	.002
Error (R x T)	39.26	279			

*p<.05, **p < .01

Table III-16 Summary of ANCOVA results (hit rates).

Summary of Age Group (between-subjects: young, old) X Incentive Type (between-subjects: loss, gain) X Run Type (within-subjects; incentivized, non-incentive) X Time (within-subjects: minute 1-4) ANOVA on hit rates with Motivation as covariate results for CTET. Results for the Time factor and interactions involving it use the linear trend analysis.

Source	Sum of Squares	df	F	p	η_p^2
Motivation	3.21	1	20.36**	<.001	.068
Age	2.25	1	14.27	<.001	.049
Incentive	.246	2	.781	.459	.006
A x I	.828	2	2.63	.074	.018

Error	43.99	279			
Time	1.30	1	101.69**	<.001	.267
T x M	.133	1	10.35**	.001	.036
T x A	.157	1	12.24	.001	.042
T x I	.008	2	.299	.742	.002
T x A x I	.012	2	.479	.620	.003
Error (time)	3.58	279			
Run Type	.002	1	.284	.594	.001
R x M	.028	1	4.26*	.040	.015
R x A	.000	1	.009	.923	.000
R x I	.129	2	9.82**	<.001	.066
R x A x I	.018	2	1.36	.257	.010
Error (Run Type)	1.84	279			
R x T	.005	1	.867	.353	.003
R x T x M	.001	1	.232	.630	.001
R x T x A	.000	1	.004	.951	.000
R x T x I	.007	2	.624	.536	.004
R x T x A x I	.006	2	.504	.605	.004
Error (R x T)	1.61	279			

*p<.05, **p < .01

Table III-17 Summary of ANCOVA results (d').

Summary of Age Group (between-subjects: young, old) X Incentive Type (between-subjects: loss, gain) X Run Type (within-subjects; incentivized, non-incentive) X Time (within-subjects: minute 1-4) ANOVA on d’ with Motivation as covariate results for CTET. Results for the Time factor and interactions involving it use the linear trend analysis.

Source	Sum of Squares	df	F	p	η_p^2
Motivation	38.76	1	10.28**	.002	.036
Age	8.80	1	2.34	.128	.008

Incentive	14.91	2	1.98	.140	.014
A x I	7.06	2	.936	.393	.007
Error	1051.86	279			
Time	10.905	1	46.00**	<.001	.142
T x M	.285	1	1.20	.274	.004
T x A	2.05	1	8.65**	.004	.030
T x I	.045	2	.094	.910	.001
T x A x I	.181	2	.381	.684	.003
Error (time)	66.14	279			
Run Type	.045	1	.244	.621	.001
R x M	.374	1	2.04	.155	.007
R x A	.229	1	1.25	.265	.004
R x I	5.05	2	13.76**	<.001	.090
R x A x I	.048	2	.130	.878	.001
Error (Run Type)	51.21	279			
R x T	.070	1	.492	.483	.002
R x T x M	.024	1	.170	.681	.001
R x T x A	.001	1	.010	.921	.000
R x T x I	.209	2	.740	.478	.005
R x T x A x I	.059	2	.211	.810	.002
Error (R x T)	39.416	279			

*p<.05, **p < .01

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Chapter IV. The Effect of Outcome Valence and Motivational Salience on Learning and Source Recognition

Abstract

We investigated explicit knowledge of learned value-based associations in a two-phase experiment. The effects of point and monetary incentives was also examined. Participants first learned to associate scenes with high or low probability (i.e., high or low motivational salience, respectively) win and loss by performing a value learning task in which the objective was to maximize points, or points and money earned on each trial. Contrary to the common assumption that win and loss outcome associations are learned equally, we found that win associations were learned better than loss associations, suggesting an advantage for outcomes with a positive valence. A subsequent source recognition task assessed explicit knowledge of the learned value associations. Regardless of learning level or incentive conditions, source recognition was superior for scenes that had previously been the optimal choice (high probability win and low probability loss) however, accurate recognition of optimal win scenes was significantly better than optimal loss scenes. These findings indicate that learning to select the optimal choice is dissociable from explicit knowledge about the outcome contingencies, especially for loss and low probability outcomes. Moreover, motivational salience is represented differentially in explicit memory for win and loss outcomes.

Introduction

The ability to predict if an action may lead to an advantageous or disadvantageous outcome is crucial for an individual to make decisions in complex environments. Such predictions are acquired through learning from past experiences. Actions resulting in a desirable outcome are more likely to be repeated in the future. Actions producing an aversive outcome, are more likely to be avoided. In complex environments, the relationships between actions and outcomes are often probabilistic rather than deterministic. Moreover, in order to make optimal decisions, individuals often need to integrate information from immediate outcomes as well as the history of outcomes produced by the same action. This type of decision is called a value-based decision because the choice was made based on a subjective value. The process of updating the value based on outcomes is called value learning. Research on value learning has a long history dating back to animal research by Thorndike (1898), Pavlov (1927) and Tolman (1948). Before going into details about the present study, it is useful to clarify the concepts related to value and value learning.

Value learning systems

A multiple-system framework of value learning has been proposed based on both animal and human behavioral studies (Dickinson, 1985; Dickinson and Balleine, 2002), as well as neural and computational evidence (Balleine and O'Doherty, 2010; Balleine et al., 2009; Daw et al., 2005; Daw and O'Doherty, 2014; Rangel et al., 2008). This multiple-system framework entails three distinct types of value learning systems: Pavlovian, habitual, and goal-directed. These systems enable agents to make predictions based on prior experience and to make decisions in different circumstances. Although the precise neural mechanisms underlying these systems are not yet fully specified, a large body of research has shown that behaviors from different learning systems are psychologically and computationally dissociable.

The Pavlovian system enables an agent to acquire associations between stimuli and outcomes. Once the association is established, the system activates simple approach and avoidance to particular stimuli. The classic example of Pavlovian learning comes from Pavlov (1927). When a neutral stimulus (bell) is repeatedly paired with an unconditioned stimulus (food), the neutral stimulus becomes a conditioned stimulus and elicits a conditioned response (salivation), which is the reflex (unconditioned) response to the unconditioned stimulus (food). There are two important differences between the Pavlovian system and other systems. First, the association formed in Pavlovian learning is between the stimulus and the outcome rather than the action and the outcome. For example, the dog salivates because the bell predicted food, and it is the food that causes salvation. Second, the Pavlovian system assigns values to a small set of biologically significant events and thus is limited to a small repertoire of inflexible behaviors (Rangel et al., 2008).

Similar to the Pavlovian system, the habitual system assigns values to stimulus-response associations. However, a key difference between the habitual system and the Pavlovian system is that habitual associations are between the action and the outcome. In other words, the outcome causes the action in habitual learning. For example, if pressing a lever provides food, a rat can learn to press the lever through repeating this action to obtain food. Although the habitual system allows agents to learn many complex behaviors, this system is still inflexible. Habitual learning is a result of repetition and extensive training. It does not allow agents to flexibly adjust their actions.

By contrast, the goal-directed system integrates causal consequences of specific actions. Dickinson (1985) argued that in goal-directed learning, agents learn to encode a representation of the action-outcome contingency and treat the outcome as an incentive or goal. In this type of learning, the system does not only assign values to actions associated with anticipated consequences, but also evaluates the rewards associated with outcomes. If the value of an outcome changes, the representation of the action-outcome contingency is modified and thus the system will update the value of an action. With the capacity of updating, agents can respond to environmental changes through goal-directed learning.

The present study examines value learning by what would be best characterized as the goal-directed system. However, it is also important to note that these three learning systems do not function in isolation and any given task is likely to involve multiple types of learning, especially in humans. The literature on how these learning systems interact and oppose one another is rich, complex (see an overview in O'Doherty, Cockburn, & Pauli, 2017) and beyond the scope and design of the current research.

Prediction Error and Value Signal

Both animal and human research has investigated the psychological, computational, and neural underpinnings of value-based decisions (see reviews Johnson & Ratcliff, 2014; Kable & Glimcher, 2009; Levy & Glimcher, 2012; Rangel, Camerer, & Montague, 2008). Studies by Schultz and colleagues (1997) provided initial evidence on the relationship between dopaminergic neurons and value signals. Their main findings were that the phasic activity of dopamine neurons encodes a prediction error (PE) — the difference between the actual reward from the outcome and the expected reward. PEs serve as a learning signal, allowing an agent to improve the prediction by continuously updating those predictions toward what was actually experienced. A positive PE represents an actual outcome that is better than expected, and has been associated with increased phasic firing rates in the midbrain dopamine neurons. By contrast, a negative PE represents an actual outcome that is worse than expected and has been associated with cessation of firing in these dopamine neurons. Together, positive PEs reinforce the current action-outcome association, while for negative PEs, the association is weakened. In addition to midbrain components, many recent studies have revealed a complex brain network for value signals, including areas such as amygdala, orbital frontal cortex, ventromedial prefrontal cortex, striatum, lateral prefrontal, and parietal cortex (see O'Doherty et al., 2017).

Behavioral and neural evidence also suggests that value signals incorporate different information such as valence (Seymour et al., 2007; Weller et al., 2007; Yacubian et al., 2006), predictiveness (motivational salience; Lang & Davis, 2006; Lin & Nicolelis, 2008), and delay between decisions and outcome (time discounting; Frederick, Loewenstein, & O'donoghue, 2002). These different aspects of value may have differential effects on different cognitive processes.

Goal-directed value learning and cognition

The essence of value learning is to associate an otherwise neutral stimulus with a value, allowing an agent to optimize behavior by learning to predict outcomes of actions. In laboratory settings, this type of learning has been studied by asking participants to perform a task in which they learn to associate stimuli with value information (e.g., valence, predictiveness of an outcome) until meeting a set performance criterion, which is typically achieved after an extensive series of exposures to the stimuli and their outcomes. Researchers have designed and utilized a variety of paradigms to examine this learning process. These paradigms use a common framework of maximizing gains and minimizing losses. In this framework, participants are expected to learn to choose the optimal choices: high probability gain and low probability loss. For example, Pessiglione and colleagues (2006) used a typical probabilistic learning task. Participants were asked to choose between novel two stimuli (abstract symbols) to maximize monetary payoff. Three pairs of stimuli were present: one pair of stimuli associated with gains, another associated with losses, and the final one associated with no financial outcome. The gain and loss stimuli were associated with a certain probability of the outcome. Participants learned to choose the high-probability gain and low probability loss after 30 trials.

Many recent studies have focused on how stimuli that have acquired learned value influence different psychological constructs, such as perceptual processing (O'Brien & Raymond, 2012), attention (Anderson, Laurent, & Yantis, 2011; Della Libera, & Chelazzi, 2009; Raymond and O'Brien, 2009), motor control (Painter, Kritikos, & Raymond, 2013), working memory (Thomas, FitzGibbon, & Raymond, 2016) and associative memory (Aberg, Müller, & Schwartz, 2017). A majority of these studies have taken a similar two-pronged approach: Stimuli from a prior value learning/value decision-making task are incorporated in a subsequent follow-up or secondary task to examine the consequences of prior learning. These studies typically assume that participants have acquired value associations during the initial learning task and then make inferences about what was learned based on performance of the secondary task. For example, in a study by Raymond and O'Brien (2009), participants performed a value learning task (VLT) prior to an attentional blink task (ABT). In the VLT, participants chose between face stimuli and learned associations with wins or losses (valence) and high or low motivational salience. Valence and motivational salience are two distinct psychological dimensions. Valence refers to whether the outcome is positive (gain) or negative (loss); motivational salience represents the outcome predictiveness of the stimuli, or the probability of obtaining an outcome by choosing a stimulus. After completion of the VLT, the learned face stimuli were presented again in the ABT in addition to a number of new face stimuli. Participants were required to distinguish if the faces were old (learned) or new. They found that recognition performance was better for faces associated with high rather than low motivational salience regardless of valence or attention constraints. In addition, when attentional resources were constrained, recognition performance was reduced for faces associated with losses but there was no effect on faces associated with wins. Therefore, the authors concluded that while effects of motivational salience seem independent of attention, valence may affect attention. In this example, the effects of valence and motivational salience were learned from the first value learning task and they assessed by a secondary ABT task.

In addition to the study by Raymond and O'Brien (2009), many studies investigating value learning involved two aspects of assigned values: valence and motivational salience. Numerous studies have investigated the effects of these two dimensions and their interaction (e.g., O'Brien & Raymond, 2012; Painter, Kritikos, & Raymond, 2013; Raymond and O'Brien, 2009). For example, using a value learning task similar to Raymond and O'Brien (2009), Rothkirch and colleagues (2013) investigated effects of valence and motivational salience on saccades. After the completion of a value learning task, participants performed a subsequent saccade task. The learned stimuli from the value learning task were presented in the secondary task. They found that saccadic latencies were shorter for previously learned stimuli associated with high versus low positive motivational salience.

While these studies provided insights about how learned value may influence subsequent cognitive processes, they assume that the underlying learning is equivalent for all stimuli and their associations if performance reaches criterion (e.g. learned to make optimal choices during the task). The finding that secondary task performance was affected by valence and motivational salience, even though the previously learned value of the stimuli was irrelevant, raises doubt about this assumption. An even more basic aspect of value learning has yet to be investigated: the assessment of explicit knowledge of the outcomes for each stimulus in the value learning phase. Prior studies have assumed equal learning and presumably equivalent knowledge of outcomes and their probabilities. The present study tests these assumptions directly.

Present study

The present study uses a value learning task similar to prior research; however, the secondary task is specifically designed to assess participants' explicit knowledge of the learned associations. We combined the Value Learning Task (VLT) modified from Raymond and O'Brien (2009) with a Source Recognition Task (SRT). The valence and the motivational salience of the stimuli were experimentally manipulated in the VLT. In the SRT, participants were asked to perform a forced choice recognition judgment and the choices included information about both valence and motivational salience for each of the learned stimuli. This allowed us to assess participants' explicit knowledge about the associations with the stimuli. In addition to participants' correct responses, we also explored participants' attribution errors.

In addition to determining whether value learning and explicit knowledge of associations are affected by the real-world significance of the outcome, we randomly assigned participants into two groups: point incentive and monetary incentive. Participants in the point incentive group only received points and performance-contingent feedback while participants in the monetary incentive group received performance based monetary rewards in addition to points and feedback. This manipulation provides insight into whether findings with artificial reward, such as points, can be generalizable to a real-world situation where outcomes have meaning, as they would when someone would gain or lose real money.

In summary, the current study addressed the following research questions: 1) What do participants know (report explicitly via source recognition) about the associations acquired in the VLT? 2) How do valence and motivational salience of the learned stimuli affect participants' explicit knowledge (source recognition)? 3) What are the types of errors participants make? How do these errors inform the representation of participants' learned associations? 4) Does monetary incentive affect value learning? If so, what aspect of value learning is impacted? Does incentive also affect subsequent source recognition?

Methods

All methods, materials, and procedures were approved by the University of Michigan Institutional Review Board.

Participants

A total of 116 participants (56 female, mean age = 18.66) were recruited for this study. The target enrollment was 92. Group size was determined based on prior pilot work and counter-balancing required by the task. All participants were recruited from the Introductory Psychology subject pool at the University of Michigan and received course credits for their participation. Participants were randomly assigned to one of the two conditions: point incentive (N = 46, 22 females, age range = 18 -21 years, mean age = 18.67 years) and monetary incentive conditions (N = 46, 23 females, age range = 18 -21 years, mean age = 18.76 years). Participants in the monetary incentive condition received a performance-based monetary reward in the VLT, while those in the point incentive condition received only feedback about points they earned. Participants were screened to ensure no history of anxiety, depression, ADHD, head injury, and no use of medications that affect cognition. For inclusion in the analyses, it was required that participants learn to a criterion of 65% accuracy for both win and loss conditions by the final block of the VLT. Those who did not meet this criterion presumably failed to understand the instructions or engage sufficiently in the task and were excluded. Seven participants were excluded for the monetary incentive condition and 17 participants were excluded for the point incentive condition. The fact that more participants had to be excluded from the point incentive than monetary incentive condition might seem due to the effects of monetary incentives. This issue will be revisited in the result section.

Apparatus

The main tasks were implemented using E-Prime version 2.0 (Psychology Software tools; http://www.pstnet.com/eprime.cfm). The apparatus used to run the tasks and record all necessary data was a Pentium 4 computer running E-Run version 2.0 on a 40 cm monitor (75-Hz refresh, 1152x864 resolution). The viewing distance was 45 cm.

Stimuli

The stimuli were acquired from the Cognitive Neuroscience Research Lab led by Adam Gazzaley (Rissman, Gazzaley, & D'Esposito, 2009), and consisted of 18 grayscale images. All images were novel photographs of landscape scenes, 225 pixels wide by 225 pixels tall.

Procedure

Participants were randomly assigned to either the point incentive or monetary incentive conditions. All participants were instructed to earn as many points as possible in the value learning task and their cumulative score was presented on the upper right corner of the screen throughout the task. In the monetary incentive condition, participants were told that they could earn a bonus up to $10 based on points earned. Their bonus was predetermined to be 3% of their final score. Participants in the point incentive condition were informed of their final point accrual but did not receive any monetary reward.

Value Learning Task

The VLT was modified based on the task by Raymond and O'Brien (2009). The present task used 6 black and white scenes as stimuli while the original task used 12 faces. On each trial, one scene appeared above a central fixation cross, and the other appeared below the cross (Figure 1a). The participant was instructed to select one of the scenes by pressing either the "F" key to select the top scene or the "J" key to select the bottom scene. The selection of a scene resulted in one of three outcomes: a win, loss or no change in points. A win outcome earned the participant 5 points, a loss outcome took away 5 points, and a no change outcome left the score unchanged. The goal of the task was to earn as many points as possible.

One pair was randomly assigned to one of the three valence conditions: win, lose and control. The win pair could result in a win or no change while the loss condition could result in a loss or no change. The control condition always led to no change. The assignment of scenes to value conditions was counterbalanced and randomized across participants.

In addition to valence, the motivational salience of the outcome was also manipulated in the win and loss pairs. One scene from each win or loss pair was associated with 80%

probability win or loss, and designated the high motivational salience scene. When the participant chose the high motivational salience scene, 80% of the time he or she would receive a valence outcome (either win or loss) while the remaining 20% resulted in a no change outcome. The other scene from each win or loss pair was associated with a 20% probability of win or loss; the low motivational salience scene. These contingencies remained constant for the entire experiment. Therefore, it was to the participant's advantage to learn to identify and select the high probability win scene for the win pair trials and the low probability loss scene for the loss trials. Win, loss, and no-change scene pairs occurred randomly and with equal probability. In addition to the randomization previously defined, the program also randomized the scene top/bottom location for a given trial. This reduced the effects of bias participants may have for preferring scenes in the top or bottom location.

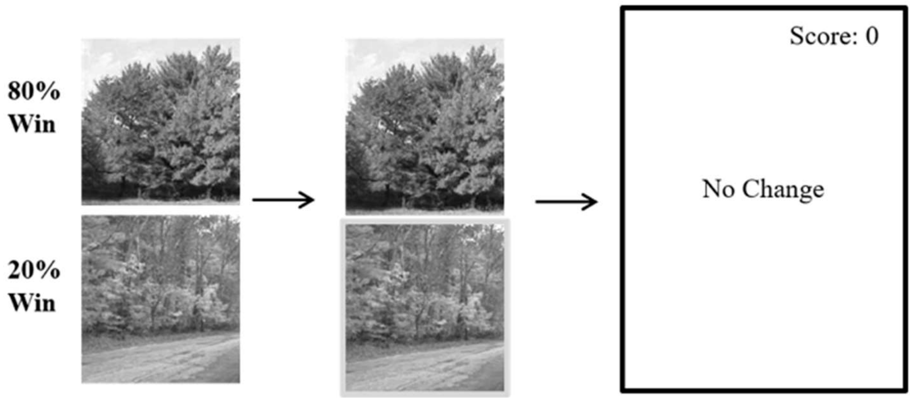
The VLT was administered in a series of five blocks. Participants were given a one-minute break between blocks. Each block contained 20 win trials, 20 loss trials, and 20 control trials, in a random order, for a total of 60 trials. The motivational salience and location probabilities described earlier for the win and loss conditions pertained for every block (see Figure for an illustration of motivational salience and optimal choices for the VLT).

For each trial in the VLT, participants were instructed to select the scene that yielded optimal outcomes for most possible points. One scene pair appeared on each trial. Once a decision was indicated, a gold border appeared around the selected scene, followed by feedback about the selection. The feedback phase presented a screen with Win (in green), Loss (in red), or No Change (in black) in the middle of the screen along with the participant's cumulative point total in the upper right corner of the screen.

Source Recognition Task

After completing the VLT, participants performed the Source Recognition Task (SRT) to evaluate their explicit memory for learned associations. This task included the 6 scenes from the VLTs and 12 new scenes. The 6 old scenes were presented 4 times each whereas the 12 new scenes were presented 2 times each, totaling 48 trials. Participants were given 6 options for classifying each scene: very likely win, occasionally win, no change, very likely lose, occasionally lose, and none (new). The "very likely" category corresponded with the high motivational salience (80%) scene while the "occasionally" category adjective represented the low motivational salience (20%) scene. No feedback was given about performance on this task.

a.



b.

Condition	Win	Loss	Control
High Motivational Salience	80% Win *	80% Loss	50% Control
Low Motivational Salience	20% Win	20% Loss *	50% Control

Figure IV-1. Diagram of the VLT.

a. Participants viewed a pair of scenes, one above and one below a fixation cross. They chose a scene by pressing one of the two designated keys and a gold border appeared around the selected scene. The screen displayed the feedback and their score after their selection. In this example, a participant selected a 20% win scene and received a “No Change” feedback. b. The table illustrates the relationship between value conditions and motivational salience in the VLT. Asterisk indicates the optimal choice for each pair. There is no optimal selection for the control condition.

1 = Very likely to win, 2= Occasionally win,
3 = No change,
4 = Occasionally lose, 5 = Very likely to lose,
6= None (new image)

Figure IV-2 Diagram of the Source Recognition Task (SRT).

The task included 6 scenes from the VLTs and 12 new scenes. Participants were given 6 choices and no feedback was given.

Results

All analyses were conducted using IBM SPSS version 24. For analyses including within-subject factors, the Greenhouse-Geisser correction was applied when sphericity was violated, and corrected degrees of freedom (rounded to the nearest integer for easier reading), *p*, and *F* values are reported below. Effect sizes for repeated measures were determined using partial eta squared. Effect sizes for post hoc t tests were calculated as indicated by Rosenthal (1991). Effects of .10 are considered small, effects of .30 are considered moderate, and effects of .50 are considered large.

Point Incentive vs. Monetary Incentive

In general, participants in the point incentive condition performed similarly to those in the monetary incentive condition. Neither the main effect nor any interactions involving the incentive type reached statistical significance for performance in the VLT or SRT. Only one exception was found in attribution errors for new scenes. Details and statistics on these effects are discussed in corresponding result sections.

As mentioned earlier in the method section, the number of participants excluded for not learning to criterion was larger for the point incentive condition (*N* = 7) compared to the monetary incentive condition (*N* = 17). To further test the relationship between incentive type and exclusion, a chi-squared test was run. The association between incentive type and exclusion was marginally significant, $X^2(2) = 3.33$, $p = 0.07$, suggesting that monetary incentives have some beneficial effect on overall performance that leads to more participants meeting the learning criteria. However, as the subsequent analyses reveal, incentive type does not affect the patterns of learning.

Value Learning

We first examined the effects of incentive type, valence, and block on participant's performance accuracy (percent correct). In the VLT, participants chose scenes from pairs to maximize gains and minimize loss. We defined an accurate response as selecting the optimal image (80% win, 20% loss), regardless of its actual outcome. For each participant, we calculated the proportion of trials within each block for which they selected the optimal image in each valence condition. These choice scores served as an index of learning over blocks and incentive condition.

The critical results are illustrated in Figure 3, which illustrates better learning of win than loss trials over blocks, and similarly for the two incentive conditions. These effects were confirmed quantitatively using a mixed analysis of variance (ANOVA) with choice performance accuracy as the dependent measure and incentive type (Point Incentive, Monetary Incentive), valence (Win, Loss), and block (1,2,3,4,5) as independent variables. Results revealed a significant main effect of valence, $F(1, 90) = 58.06$, $p < .001$, $\eta_p^2 = .393$, indicating that overall participants were more likely to select the optimal image in the win than loss condition. The main effect of block was also significant, $F(4, 239) = 100.91$, $p < .001$, $\eta_p^2 = .529$. The likelihood that participants' would select the optimal scene increased over blocks, $M = .71 < .85 < .90 < .93 < .94$ (See Table 1 for value learning performance for each block in all conditions). The main effect of incentive type was not significant, $F(1,90) = 1.33$, $p = .252$, $\eta_p^2 = .015$. Participants in both incentive type conditions performed similarly, and there were no interactions with this variable, $F < 1.33$, $p > .525$, $\eta_p^2 < .015$. The interaction between valence and block just reached significant level, $F(3, 90) = 2.76$, $p = .049$, $\eta_p^2 = .030$. Post hoc paired samples t tests showed that win associations were learned significantly better in each block, $t > 3.54$, $p < .001$. The marginal status of this interaction is likely due to the near ceiling performance in the last two blocks of the win condition contributing to numerically smaller mean differences between win and loss.

For the no-change pair, neither scene is an optimal choice. Therefore, for each counterbalance order, one no-change scene was arbitrarily selected as the correct scene. Probability of the selecting the scene was examined by a repeated-measures ANOVA as a function of incentive type (Point Incentive, Monetary Incentive) and block (1,2,3,4,5). No effects were statistically significant, all $F < 3.03$. The average of choosing an arbitrarily selected scene in the pair was .51 across all participants.

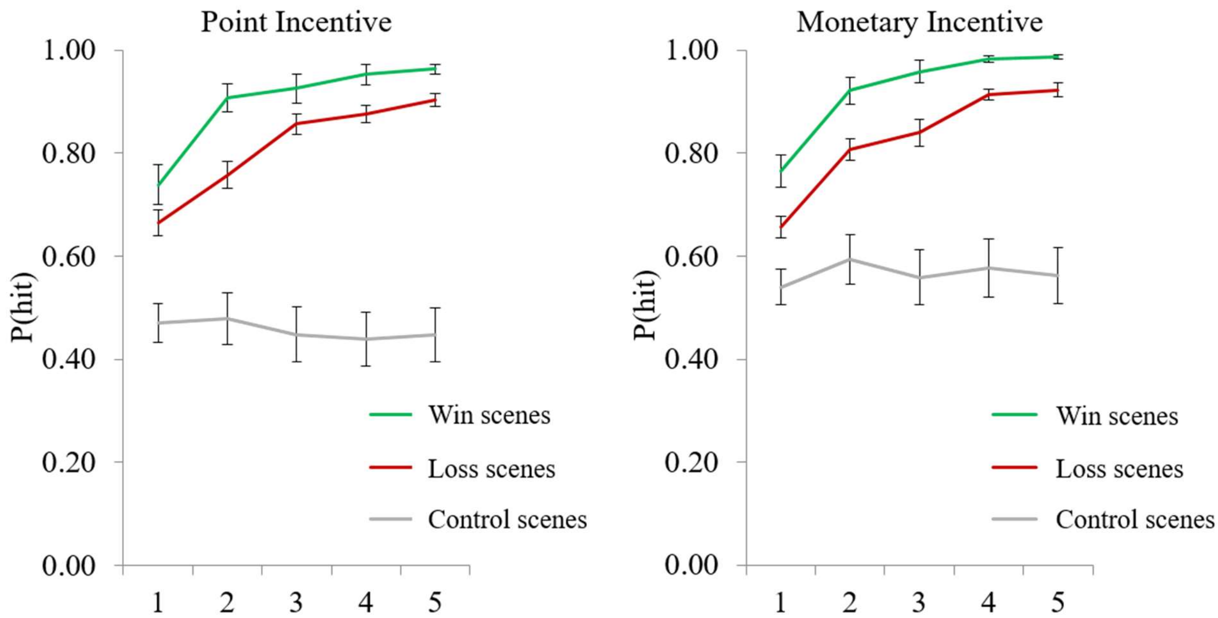


Figure IV-3 Value learning performance

Mean value learning accuracy (percent correct ± standard error) as a function of incentive type, valence, and block. The graph represents the average probability of choosing the optimal choice over 5 blocks for win, loss, and control (no-change) pairs. Error bars indicate standard errors.

Table IV-1 Percent correct means and standard errors (SE) for value learning performance.

		Blocks									
		Block 1		Block 2		Block 3		Block 4		Block 5	
Performance		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Point Incentive	Win	.74	(.04)	.91	(.03)	.93	(.03)	.95	(.02)	.96	(.01)
	Loss	.67	(.02)	.76	(.03)	.86	(.02)	.88	(.02)	.90	(.01)
	Control	.47	(.04)	.48	(.05)	.45	(.05)	.44	(.05)	.45	(.05)
Monetary Incentive	Win	.77	(.03)	.92	(.03)	.96	(.02)	.98	(.02)	.99	(.00)
	Loss	.66	(.02)	.81	(.02)	.84	(.03)	.91	(.01)	.92	(.01)
	Control	.54	(.04)	.59	(.05)	.56	(.05)	.58	(.06)	.56	(.05)

Source Recognition

The SRT evaluated participants' explicit knowledge of the associations learned in the VLT. In a forced choice recognition task, participants indicated their knowledge of the prior outcome associated with each image from the VLT as well as novel images that had not appeared in that task.

We first examine participants' general ability to distinguish between old and new scenes. The criteria for correctly classifying an old scene is to choose any category except for new in the source recognition task (note that participants can correctly identify an old scene but still make a mistake in terms of the scene identity). We performed a mixed ANOVA on scene recognition as a function of incentive type (Point Incentive, Monetary Incentive), and scene type (Old, New). Participants showed similar recognition accuracy for new ($M = .94$, $SE = .01$) and old scenes ($M = .95$, $SE = .008$), $F < 1$ and performance between point incentive and monetary incentive group did not differ, $F(1, 90) = 1.99$, $p = .162$, $\eta_p^2 = .022$.

A mixed ANOVA compared recognition accuracy as a function of incentive type (Point Incentive, Monetary Incentive), valence (Win, Loss), and motivational salience (High, Low). The main effect of incentive was not significant, $F < 1$, nor were any of its interactions, all $Fs < 1$. Therefore, the key results illustrated in Figure 4 collapse across the two incentive conditions. Results revealed a significant main effect of motivational salience, $F(1, 90) = 109.16$, $p < .001$, $\eta_p^2 = .548$, indicating better memory for high motivational salience scenes than low motivational salience scenes. Although the main effect of valence was not significant, $F < 1$, the interaction between motivational salience and valence was significant, $F(1, 90) = 142.13$, $p < .001$, $\eta_p^2 = .612$. Follow-up paired samples t tests revealed that participants' source recognition was significantly better for the high salience scene than the low salience scene in the win pair,

$t(91) = 19.48$, $p < .001$, $r = .80$. By contrast, participants' classification accuracy was better for the low motivational salience scene than the high motivational salience scene in the loss pair, but this effect did not survive Bonferroni correction, $t(91) = 2.18$, $p = .032$, $r = .14$. When comparing the source memory for the two optimal choices, participants' source recognition was significantly better for the high motivational salience win scene than the low salience loss scene, $t(91) = 6.76$, $p < .001$, $r = .42$. Therefore, recognition was better for scenes that had previously been optimal choices, although this effect was considerably more pronounced for win than for loss scenes.

Participants were also better able to identify the high salience win scene than the no-change scenes, $t(91) = 6.26$, $p < .001$, $r = .39$. Yet, follow-up Bonferroni corrected comparisons showed that recognition accuracy for no-change scenes was significantly better than for the low salience win scene, as well as high salience loss scenes, $t(91) = 13.82$, $p < .001$, $r = .65$; and $t(91) = 4.27$, $p < .001$, $r = .28$. The recognition accuracy for no-change scenes was numerically better than low salience loss scene, but the difference didn't survive after Bonferroni correction, $t(91) = 2.14$, $p = .035$, $r = .13$.

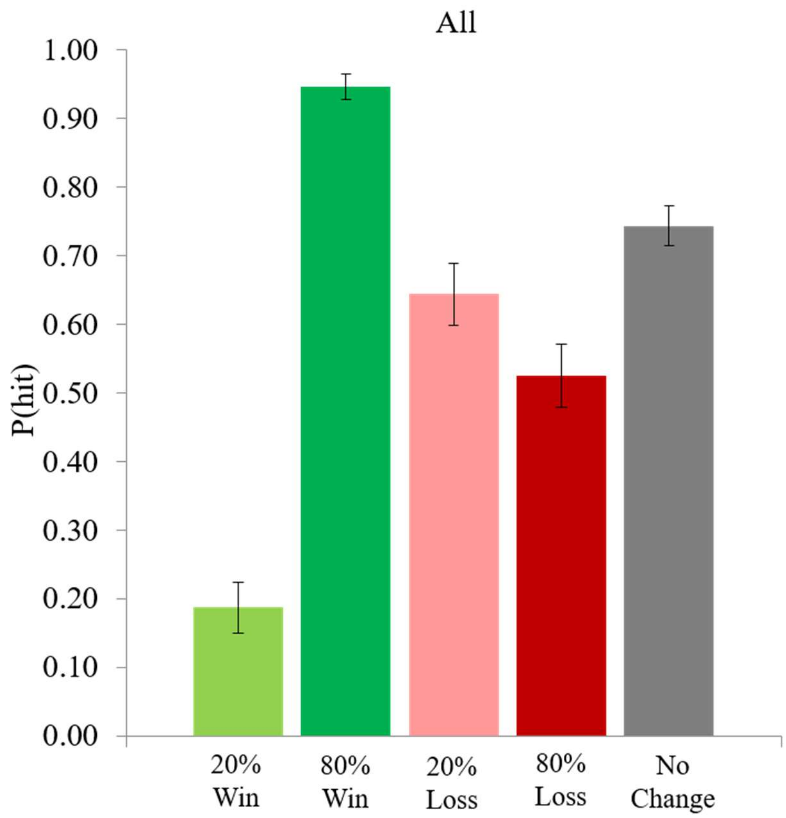


Figure IV-4 Source recognition accuracy.

Mean recognition accuracy (percent correct ± standard error) as a function of valence, and motivational salience collapsing across incentive conditions. The graph depicts average recognition accuracy for each scene. Error bars indicate standard errors.

Attribution Errors

Win and Loss Scenes Misattribution

The SRT data suggest that regardless of incentive condition, participants acquire different information about win and loss pairs. To gain more insight into what information participants acquire about these pairs, we examined attribution errors. Valenced scenes could be associated with four different types of errors: Salience Error (i.e. a participant misattributed a low salience scene for a high salience scene or vice versa), Valence Error (i.e. a participant misattributed a loss scene as a win scene, or vice versa), No Change Error (i.e. a participant misattributed a loss/win scene as a no change scene), New Error (i.e. a participant misattributed a win/loss scene as a new scene). Two questions are especially relevant: 1) What types of errors did participant make for low salience win scenes, where recognition accuracy was lowest? 2) What types of errors did participant make for the two loss scenes both of which were associated with accuracy levels less than 70%? As Figure 5 illustrates, no change errors were most prominent for low salience win scenes, which makes sense because this was the outcome associated with this scene 80% of the time, yet also suggests poor recognition of the scene's valence. For low salience loss scenes, participants made relatively fewer errors and no change errors were also most common. For the high salience loss scenes, however, salience errors are most prominent, suggesting that valence but not salience was encoded for loss outcome in contrast to the high salience, win outcome, where valence and salience were accurately recognized.

In order to examine these effects quantitatively, a mixed ANOVA was conducted on recognition errors with the between-subject factor of incentive type (Point Incentive, Monetary Incentive), and the within-subject factors valence (Win, Loss), salience (High, Low), and error type (Salience, Valence, No Change, New). Here we focus on the effects related to error type for two reasons (See supplemental table 1 for full details of the ANOVA). First, some effects from the misattribution analyses are redundant with recognition accuracy analyses. For example, there was a significant interaction between valence and motivational salience on recognition errors, $F(1, 90) = 122.40$, $p < .001$, $\eta_p^2 = .576$. Participants made fewer errors in optimal choices from the value learning task. The recognition accuracy results indicate that participants were more likely to identify the optimal scene accurately. Second, due to the number of factors, this ANOVA resulted in many main effects and interactions. A more focused analysis allows us to address our two research questions. Results revealed that the valence x motivational salience x error types interaction was significant, $F(1, 166) = 8.46$, $p < .001$, $\eta_p^2 = .086$, indicating that participants made different patterns of errors for each the four valenced scenes. For the low salience win scene, a follow-up ANOVA revealed a significant main effect of error type, $F(2, 164) = 41.69$, $p < .001$, $\eta_p^2 = .314$, indicating the most common misattribution was no change ($M = .47$, $SE = .05$). Similarly, the low salience loss scenes were also mistaken as no change scenes ($M = .20$, $SE = .04$), $F(2, 174) = 13.01$, $p < .001$, $\eta_p^2 = .125$. However, the high salience loss scene was most likely mistaken for a low salience loss scene ($M = .32$, $SE = .04$), $F(2, 153) = 28.93$, $p < .001$, $\eta_p^2 = .241$. Thus the statistical indices support the key effects evident in Figure 5, and confirm that the low salience scenes for both valences were typically mistaken for no-change scenes; however high salience loss scenes were encoded accurately for valence but not for salience.

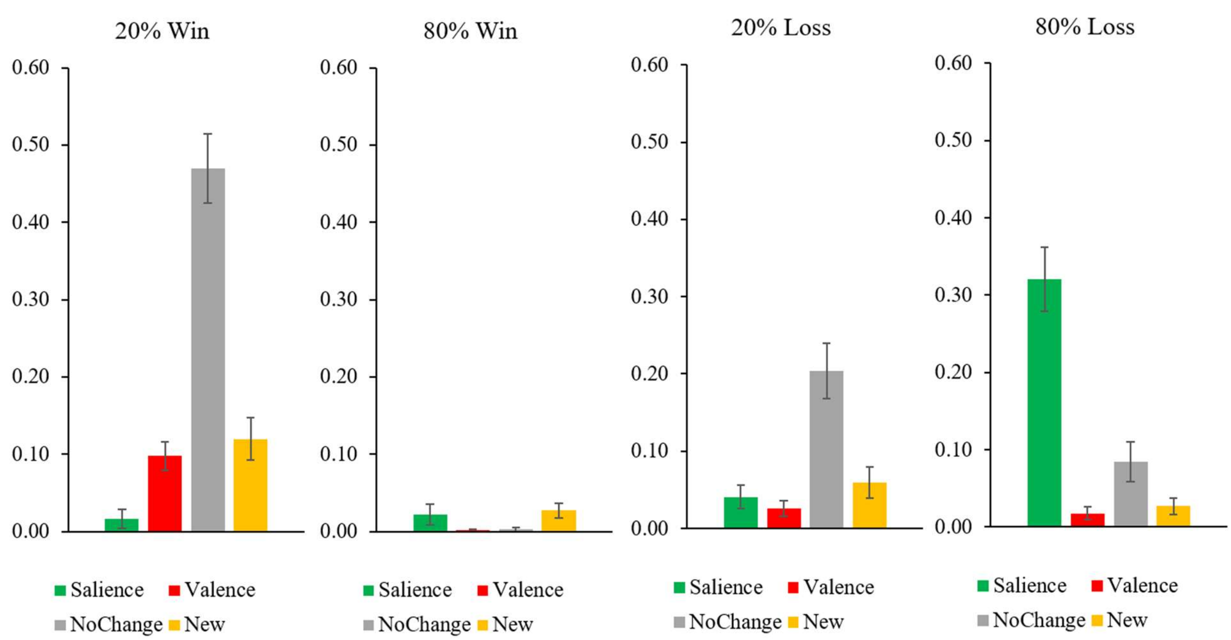


Figure IV-5 Mean recognition error rate.

Mean recognition error rate (percent error ± standard error) as a function of valence, motivational salience, and error type. The bars represent the average misattribution errors by scene type. Error bars indicate standard errors.

Misattribution of No-Change Scenes

To examine the attribution errors for the no change scenes, a mixed ANOVA was performed as a function of incentive type (Point Incentive, Monetary Incentive) and error type (Low Salience Win, High Salience Win, Low Salience Loss, high salience loss, New). The main effect of error type was significant, $F(3, 243) = 10.24$, $p < .001$, $\eta_p^2 = .102$. Participants were most likely to misidentify a no change scene as a low salience loss scene ($M = .12$, $SE = .02$), followed by high salience loss scene ($M = .06$, $SE = .01$), new scene ($M = .04$, $SE = .01$), low salience win scene ($M = .02$, $SE = .01$), and high salience win scene ($M = .01$, $SE = .01$). No other effects were statistically significant, all $F < 2.83$, $p > .10$.

Misattribution of New Scenes

As indicated in the Source Recognition section, participants in general had no difficulty distinguishing the new scenes ($M = .94$, $SE = .01$) from the old scenes ($M = .95$, $SE = .008$), so errors were rare. To examine the attribution errors for the new scenes, a mixed ANOVA was performed as a function of incentive type (Point Incentive, Monetary Incentive) and error type (Low Salience Win, High Salience Win, Low Salience Loss, high salience loss, New). The main effect of error type was significant, $F(1, 130) = 13.50$, $p < .001$, $\eta_p^2 = .130$. Participants were most likely to misidentify a new scene as a no change scene ($M = .04$, $SE = .09$), followed by low salience loss scene ($M = .006$, $SE = .003$) and high salience loss scene ($M = .006$, $SE = .002$), low salience win scene ($M = .005$, $SE = .01$), and high salience win scene ($M = .01$, $SE = .01$). The interaction between incentive type and error type was also significant, $F(1, 130) = 4.96$, $p < .05$, $\eta_p^2 = .052$. Participants who received points were most likely to misidentify a new scene as a no change scene ($M = .06$, $SE = .01$) compared to other scenes, $F(1, 49) = 12.86$, $p < .01$, $\eta_p^2 = .222$. By contrast, participants who received monetary incentive showed similar error rates across different error types, $F(1, 63) = 2.06$, $p = .149$, $\eta_p^2 = .044$. Numerically, participants in monetary incentive group were most likely to misidentify a new scene as a no change scene ($M = .02$, $SE = .01$) compared to other scenes.

Equal vs. Unequal Learners

The differences in source recognition for win and loss scenes may reflect differences in the strengths of the associations learned to win outcomes relative to loss outcomes. That is, the learning advantage for win scenes may have led to more accurate explicit knowledge of the outcome associated of the optimal win scene (i.e., high salience win scenes) compared to the optimal loss scene (i.e., low salience loss scenes). If differential learning levels is the basis for differences in recognition performance, then people who performed equally well in the win and loss conditions should not show different patterns of source recognition memory. To test this hypothesis, we performed a median split separating participants in groups with low and high win-loss learning differences.

We first calculated the overall learning differences between the win and loss conditions by subtracting the probability of choosing the optimal choice averaged over 5 blocks for the loss condition from the average for the win condition. Then we determined the median for this difference to be 0.085. Participants with scores lower or equal to the median of the the win-loss learning difference, either learned loss better than win or they learned win and loss outcomes approximately equally well. This group is called equal learners because very few participants learned loss better than win (only 6 of 46 participants learned loss 5% or greater better than win). Participants who had their win-loss learning difference higher than the median learned win better than loss, and they are referred to as unequal learners.

Value Learning

The learning curves for equal and unequal learners are displayed in Figure 6, which shows clearly that equal learners achieved approximately equivalent levels of performance for win and loss scenes across all 5 block, whereas unequal learners consistently performed worse for loss than win scenes. To characterize the effects of this median split quantitatively, the choice scores on the VLT were analyzed in a mixed ANOVA with the between-subject factors learner type (Equal, Unequal) and incentive type (Point Incentive, Monetary Incentive), and the within-subject factors valence (Win, Loss), and block (1,2,3,4,5). Results of the effects of incentive type, valence, and block followed the same pattern as the original ANOVA (See supplemental table 2 for details). None of the effects involving incentive condition reached statistical significance. Although the effect of learner type was not significant, $F < 1$, the interaction between valence and learner type was significant, $F(1, 88) = 97.45$, $p < .001$, $\eta_p^2 = .525$. Follow-up paired sample t tests demonstrated that this interaction resulted from significantly better value learning performance for win than loss outcomes in unequal learners, $t(45) = 19.39$, $p < .001$, $r = .79$, in contrast with approximately equivalent performance for win and loss learning performance in equal learners, $t(45) = .699$, $p = .488$, $r = .04$. Moreover, the three-way interaction learner type x valence x block was significant, $F(3, 235) = 5.59$, $p < .01$, $\eta_p^2 = .060$. A follow-up repeated-measures ANOVA indicated that the interaction between valence and block was significant for unequal learners, $F(2, 112) = 7.25$, $p < .001$, $\eta_p^2 = .139$, but not for equal learners, $F(3, 127) = 1.05$, $p = .369$, $\eta_p^2 = .023$. Paired sample t-tests revealed that unequal learners acquired win outcomes better than loss outcomes in every block, all $t > 6.72$, all $p < .001$, all $r > .53$. By contrast, equal learners acquired win and loss outcomes similarly for the first four blocks, all $t < 1.4$, $p > .15$, however for block 5 win outcomes were better learned than loss outcomes, $t(45) = 2.34$, $p < .05$, $r = .19$.

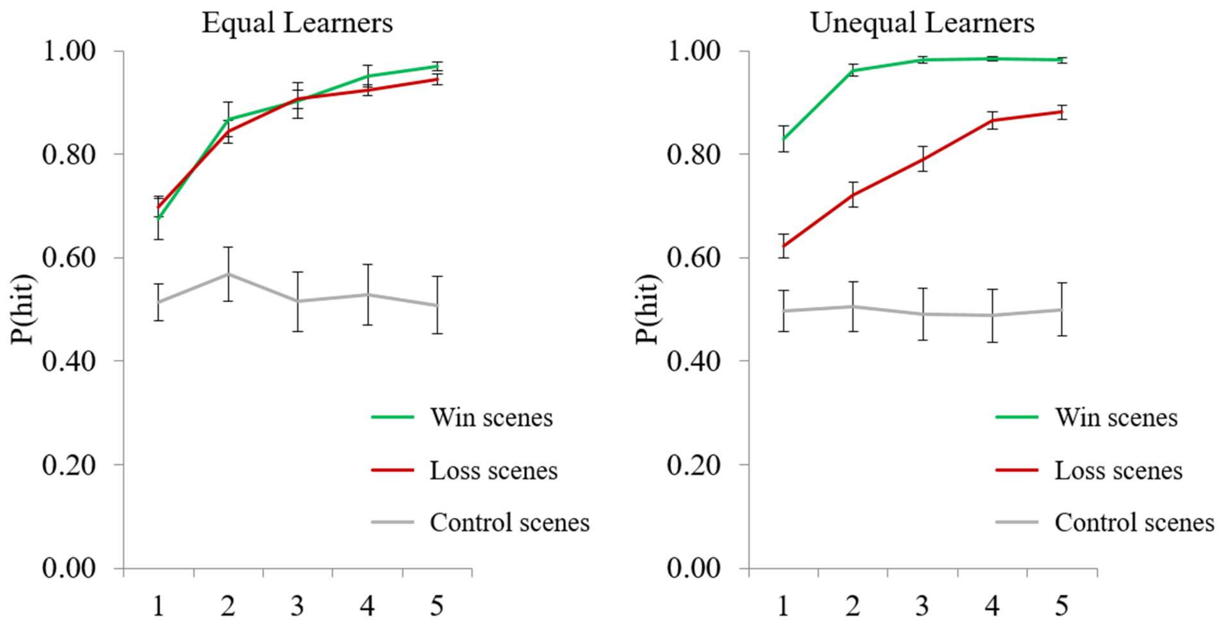


Figure IV-6 Value learning performance for equal and unequal learners.

Mean value learning accuracy (percent correct ± standard error) as a function of learner type, valence, and block. The graph represents the average probability of choosing the optimal scene over 5 blocks for win, loss, and no-change pairs. Error bars indicate standard errors.

Source Recognition

Figure 7 illustrates the critical results. For both learner types, performance was the best when identifying high salience win scenes and the worst for the low salience win scenes. Identification of the no-change scenes was also similar for both learner type. Critically, both groups identified optimal win scenes more accurately than optimal loss scenes. This was true even for equal learners, whose choice performance indicates approximately equivalent knowledge of which scene to select when presented with a win or a loss pair. Nevertheless, equal learners were no better at identifying the low salience loss scene than unequal learners, and were actually worse at distinguishing low from salience loss scenes than the unequal learners. That is, while equal learners had similar identification accuracy for high and low salience loss scenes, unequal learners identified high salience loss scenes less accurately compared to low salience loss scenes. Together, these results suggest that regardless of whether win and loss associations were learned equally well, the motivational salience attribution was different between win and loss scenes. Therefore, learning level alone cannot explain the valence-based difference in source recognition performance.

These effects were confirmed quantitatively using a mixed ANOVA on recognition accuracy as a function of learner type (Equal, Unequal), incentive condition (Point Incentive, Monetary Incentive), valence (Win, Loss), and motivational salience (High, Low). Results on the effects of incentive condition, valence, and motivational salience followed the same pattern as the earlier ANOVA (See supplemental table 3 for details). Although the main effect of learner type was not significant, $F<1$, there was a significant interaction between learner type and incentive condition, $F(1, 88) = 6.93$, $p = .01$, $\eta_p^2 = .073$. Equal learners who received monetary incentives performed better than those who received points (Money: $M = .67$, $SE = .05$; Point: $M = .51$, $SE = .06$), $t(44) = 2.21$, $p < .05$, $r = .31$. For unequal learners, the pairwise comparison between Monetary Incentive and Point Incentive was not significant (Money: $M = .51$, $SE = .04$; Point: $M = .59$, $SE = .03$), $t(44) = 1.44$, $p = .157$, $r = .21$. The three-way interaction learner type x valence x motivational salience was also significant, $F(1, 88) = 7.61$, $p < .01$, $\eta_p^2 = .080$. While unequal learners showed better recognition for scenes that had previously been optimal choices (i.e. the high salience win scene and the low salience loss scene, $t(45) = 19.86$, $p < .001$, $r = .89$, and $t(45) = 2.92$, $p < .01$, $r = .30$, respectively), equal learners better identified high salience win scenes, $t(45) = 10.65$, $p < .001$, $r = .71$, but showed approximately equivalent performance for the loss scenes, $t(45) = .21$, $p = .833$, $r = .02$. For both equal and unequal learners, source recognition was significantly better for high salience win scene compared to low salience loss scene, $t(45) = 4.67$, $p < .001$, $r = .40$, and $t(45) = 4.87$, $p < .001$, $r = .44$, respectively.

Performance for no-change scenes followed the general pattern reported across both groups, except that unequal learner identified no-change and low salience loss scenes equally well (See supplemental table 4 for details).

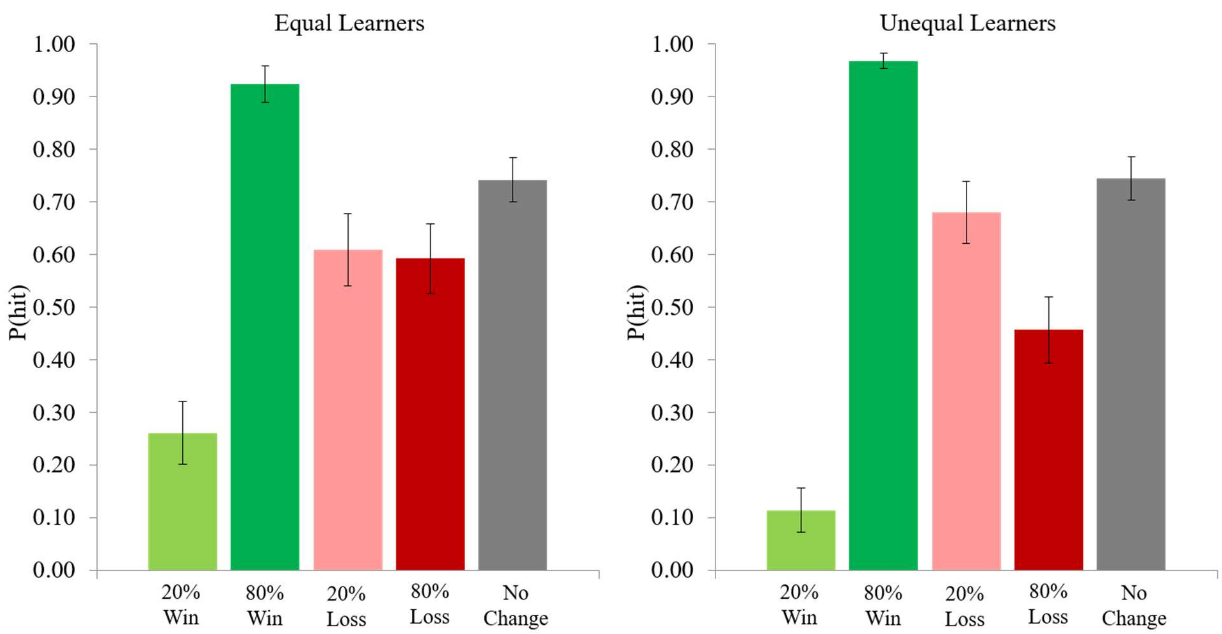


Figure IV-7 Source recognition accuracy for equal and unequal learners.

Mean recognition accuracy (percent correct ± standard error) as a function of learner type, valence, and motivational salience. The graph depicts the average recognition accuracy for each scene type. Error bars indicate standard errors.

Discussion

Win Associations Are Learned Better Than Loss Associations

We used a value learning task to imbue scenes with different valences and different levels of motivational salience. Through performing the VLT across a series of 300 trials, participants learned associations with a high or low probability win or loss for each of 6 different scenes. We were surprised to find that action-outcome associations for win associations were learned significantly better overall than for loss associations. This result was unexpected because learning differences did not figure prominently in prior reports with the VLT. Moreover, the computation of prediction errors (PEs) should be the same for both win and loss condition. PEs only concern the differences between expected outcome and actual outcome, regardless of valence. A positive PE represents an actual outcome better than expected, while a negative PE codes an actual outcome worse than expected. The VLT structure manipulates the expected values (-.8x, -.2x, .2x, .8x, where x is the performance score value involved) to be symmetrical between win and loss condition.

Prompted by these results, a closer examination of prior studies using a VLT similar to the one used here, we found trends towards a similar learning asymmetry: win associations tended to better learned than loss associations (e.g. Chapman, Gallivan, & Enns, 2015; Pessiglione et al., 2006; Rothkirch et al., 2017; Rutherford, O'Brien, & Raymond, 2010). For some of the studies that did not find statistical significant effect or did not report the statistics in the VLT, the numerical pattern is consistent with that reported here (e.g. Painter, Kritikos, & Raymond, 2013; Raymond & O'Brien, 2009).

There are at least two potential explanations for this learning difference between win and loss, and they may not be mutually exclusive. First, it may be the product of the task structure. In other words, although the task structure appears to be symmetrical between win and loss condition, the cumulative values over time may be different for win and loss condition. The optimal choices are the high salience win and low salience loss. Participants might learn faster for win optimal choice because the high probability associated with it is more likely to provide useful feedback (win) to update the representation. For the loss pair, choosing the low probability associated stimuli often leads to no change outcome (80% of the time) and thus participants might take longer to update the representation of action-outcome contingency. The second possible explanation for the difference is that there actually are two different mechanisms for learning win and loss associations that operate on different time scales, such that learning win outcome associations is more efficient. Finding that gains and losses may be mediated by different neural pathways from several neuroimaging studies might lend some support for this claim (e.g., Knutson et al., 2001; Matthews et. al., 2004; Yacubian et. al., 2006).

This finding that win associations are learned better than loss, is important because it affects the findings as well as interpretations of the secondary tasks often included in studies of value learning. Given that multiple research groups have adopted a similar approach to study value learning, it is important for future studies to clarify and investigate this win-loss difference.

Source Recognition and Attribution Errors

After completing the VLT, participants performed the SRT to assess their explicit knowledge of the association learned for each image, and to distinguish them from novel images. We found several interesting findings. First, source recognition was significantly better for the high salience scene than the low salience scene in the win pair, while source recognition tended to be better for the low salience scene than the high salience scene in the loss pair. Thus, source recognition was superior for scenes that had previously been the optimal choice. The source recognition pattern matched with the selection history in the VLT. Critically, this effect was significantly more pronounced for win than for loss scenes. Second, the source recognition for low salience win scenes was the worst among all scenes. Participants were most likely to make a no-change error, indicating that there was relative insensitivity to the win outcome if they were rare. Third, similar to the low salience win scene, no-change errors are most common for low salience loss scenes, however for low salience scenes participants were more sensitive to loss than to wins. For high salience scenes the opposite appears to be true, except that participants when they erred in recognizing high salience loss scenes, they misidentified the scene as a low salience loss scene, indicating that valence had indeed been encoded.

Given the superior performance for the win relative to the loss condition in the VLT, we conducted a median split to compare source recognition of participants who had learned associations with win and loss outcomes relatively equally well to those who learned win associations better than loss. Both groups showed the same recognition performance for the win scenes, with the best recognition of high salience win scenes. For both groups, these scenes were recognized better than either type of loss scene, even for equal learners. The only difference in source recognition was the relative performance on high and low salience loss scenes: Equal learners, recognized these equally well; unequal learners, recognized low salience loss scenes better than high salience loss scene. These results indicate that the highly accurate identification of the optimal (high salience) win scenes relative to optimal (low salience) loss scenes does not depend on learning level. Even participants who learned win and loss associations equally well showed a striking asymmetry in the identification accuracy (source recognition) for optimal win and loss scenes: the valence of loss was recognized, but salience information for losses was relatively impoverished. This was true for both equal and unequal learners despite group differences in recognition levels for high and low salience loss scenes. These results suggest a previously unreported dissociation between value based choice performance and explicit knowledge of the outcome contingencies, especially for loss and low probability outcomes. Furthermore, motivational salience is represented differentially in explicit memory for win and loss outcomes.

To our knowledge, this is the first study to investigate the explicit knowledge of learned value associations. Source recognition and attribution errors are integral parts of participants' explicit knowledge of the learned action-outcome associations and should be discussed together. The attribution error findings showed that while low salience scenes for win and loss were typically mistaken for no-change scenes, high salience loss scenes were encoded accurately for valence but not for salience because they were most likely mistaken for a low salience loss scene. The error patterns in win and loss seem to be consistent with the strategy win-stay, lose-shift such that participants are more likely to stay with the high probability win while they are more exploratory following a high probability loss (Nowak & Sigmund, 1993). The fact that no-change scenes were most likely mistaken for loss scenes seems to also support this interpretation. Compared to loss outcome associations, win outcome associations seemed to be acquired more efficiently, suggesting that win and loss learning may operate on different time scales.

Our findings are also consistent with neuroimaging studies that motivational salience and valence may be mediated by different neural networks and interact differentially in the representation of action-outcome associations (Anderson et al., 2003; Cooper & Knutson, 2008; Jensen et al., 2007; Litt et al., 2010; Small et al.,2003). In addition, studies found that striatum activated for both valence and salience signals (Cooper & Knutson, 2008; Litt et al., 2010). This suggests that striatum may be the common area where representations are updated and implemented.

Monetary Incentives Did Not Affect Patterns of Value Learning or Source Recognition

We did not find performance differences between the point incentive group and the monetary incentive group. Participants showed a similar level of value learning and source recognition performance. For attribution errors, we found that the error pattern for new scenes was different between point incentive and monetary incentive participants. Participants who received monetary incentives made similar levels of errors across different error types while participants who received points misidentified new scenes as no change scenes more frequently compared to other error types. However, it is important to note that participants made the fewest errors in new scenes compared to other types of scenes. Moreover, participants in the two incentive groups did not differ in the number of errors they made. Therefore, we interpret this effect as a chance finding.

We also found that more participants had to be excluded from the point incentive than monetary incentive group, but this pattern was not statistically significant. The results of monetary incentive were consistent predictions from neuroscientific findings (Haber & Knutson, 2010; Daniel & Pollmann,2010). If monetary incentives and performance-contingent feedback share the same neural mechanism in reward circuitry, receiving monetary incentives in addition to performance performance-contingent feedback may not improve performance. Performance-contingent feedback may serve as the reward to update participants' representation of action-outcome associations. Therefore, monetary incentives do not improve value learning or source recognition, but it might help to motivate participants to reach performance criteria. The similar results from point and monetary incentive group from our study suggest that using performance-based feedback, points in our study, can be generalizable to a more real-world situation.

Limitations and Future Directions

In the current study, a median split was conducted to investigate whether source recognition was influenced by the value learning difference between win and loss condition. The common concern in conducting median splits is a reduction of power and an increase in the potential for errors (Irwin & McClelland, 2003). However, Iacobucci and colleagues (2015) conducted a simulation study showing that the use of a median split is as good as a continuous variable when the primary interest is to investigate group differences free of multicollinearity. A more important concern for the current study is that the median split resulted in the loss of information about individual variability. For example, participants who performed higher than the median were classified in the "unequal learner" group regardless if they were only slightly above the median or much higher. Based on our findings, we cannot determine whether the learning pattern differences between equal and unequal learners were due to their experience during the task or group differences in terms of learning mechanisms. Future studies can address this issues by testing whether the learning patterns are stable across different experimental sessions. This would help to clarify whether these learning patterns are more state-like experience-driven or more trait-like individual differences.

To better explain the superior value learning for win outcomes relative to loss outcomes, we plan to use a computational learning theory, specifically reinforcement learning, to build computational models of the value learning task. The computational model can provide precise accounts of trial-by-trial performance, which is much more challenging in empirical studies. This theory can be used to provide not only interesting explanations of qualitative phenomena in aggregate, but also insights into the nature of individual differences.

Appendix C.

Table IV-2 Summary of ANOVA results for attribution errors analysis.

Source	Sum of Squares	df	F	p	η_p^2
Incentive Type	.039	1	.855	.358	.009
Error	4.16	90			
Valence	.003	1	.101	.751	.001
V x I	.045	1	1.48	.227	.016
Error (Valence)	2.73	90			
Motivational Salience	1.62	1	75.27**	< .001	.455
M x I	.018	1	.828	.365	.009
Error (MS)	1.94	90			
Error Type	5.13	2	31.37**	< .001	.258
ET x I	.039	2	.237	.833	.003
Error (ET)	14.72	222			
V x MS	3.41	1	122.40**	< .001	.576
V x MS x I	.003	1	.110	741	.001
Error (V x MS)	2.51	90			
V x ET	3.34	2	19.98**	< .001	.182
V x ET x I	.099	2	.590	.584	.007
Error (V x ET)	15.05	214			
MS x ET	8.79	3	66.81**	< .001	.426
MS x ET x I	.062	3	.468	.670	.005
Error (MS x ET)	11.83	225			
V x MS x ET	1.36	2	8.46**	<.001	.086
V x MS x ET x I	.235	2	1.46	.237	.016
Error (V x MS x ET)	14.52	166			

*p<.05, **p < .01

Table IV-3 Summary of ANOVA results for learner type analysis on value learning performance.

Source	Sum of Squares	df	F	p	η_p^2
Incentive Type	.096	1	1.25	.266	.014
Learner Type	.05	1	.061	.805	.001
I x L	.56	1	.056	.396	.008
Error	6.72	88			

Valence	1.84	1	117.41**	< .001	.572
V x I	.031	1	1.98	.163	.022
V x L	1.53	1	97.45**	< .001	.525
V x I x L	.021	1	1.33	.252	.015
Error (Valence)	1.38	88			
Block	6.61	3	100.48**	< .001	.533
B x I	.024	3	.36	.762	.004
B x L	.12	3	1.83	.149	.020
B x I x L	.16	3	2.49	.067	.028
Error (block)	5.79	238			
V x B	.131	3	2.93*	.040	.032
V x B x I	.059	3	1.32	.262	.015
V x B x L	.250	3	5.59**	<.01	.060
V x B x I x L	.042	3	.938	.442	.011
Error (V x B)	3.93	235			

*p<.05, **p < .01

Table IV-4 Summary of ANOVA results for learner type analysis on source recognition performance.

Source	Sum of Squares	df	F	p	η_p^2
Incentive Type	.18	1	.906	.344	.010
Learner Type	.13	1	.679	.412	.008
I x L	1.37	1	6.93*	.010	.073
Error	17.34	88			
Valence	.020	1	.162	.688	.002
V x I	.058	1	.468	.496	.005
V x L	.005	1	.040	.843	.000
V x I x L	.098	1	.788	.377	.009
Error (Valence)	10.89	88			
Motivational Salience	9.37	1	106.93**	< .001	.549
MS x I	.030	1	.343	.559	.004
MS x L	.003	1	.033	.856	.000
MS x I x L	.015	1	.174	.678	.002
Error (MS)	7.72	88			
V x MS	17.60	1	149.93**	< .001	.630
V x MS x I	.001	1	.010	.920	.000
V x MS x L	.893	1	7.61**	<.01	.080

V x MS x I x L	.000	1	.002	.967	.000
Error (V x MS)	3.93	235			

*p<.05, **p < .01

Table IV-5 Summary of Bonferroni-corrected pairwise comparisons for equal and unequal learners on source recognition performance.

Learner type	Comparison	df	t	p	r
Equal	20%Win-No Change	45	8.04**	< .001	.566
Learner	80%Win-No Change	45	3.90**	< .001	.329
	20%Loss-No Change	45	2.13	.039	.171
	80%Loss-No Change	45	2.13	.039	.195
Unequal	20%Win-No Change	45	12.10**	< .001	.745
Learner	80%Win-No Change	45	4.96**	< .001	.471
	20%Loss-No Change	45	.949	.348	.094
	80%Loss-No Change	45	3.90**	< .001	.372

**p < .01

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Chapter V. General Discussion

Most researchers on attention, have, at one time or another, succumbed to the temptation of beginning their presentation with the well-worn William James quote "Everyone knows what attention is…" and then devoting the rest of their talk to how attention turns out to be a much more complicated phenomenon than our intuition suggests. Perhaps less well-known are his quotes on how motivation and value influence our attention and memory – issues which this dissertation demonstrates are at least equally as complex.

It is our attitude at the beginning of a difficult task which, more than anything else, will affect its successful outcome. — William James

Chapters II and III demonstrate the sometimes-paradoxical effects of incentive on attentional performance, examine which aspects of attention and cognitive control may be most sensitive to those manipulations, and take steps towards elucidating the cognitive-motivational states and traits that may mediate those effects. Chapter II manipulated incentive between subjects and found that incentive tended to have no effect or a small beneficial effect on the focused attention of young adults and decreased their subjective reports of mind-wandering. In contrast, older adults had worse performance and more mind-wandering under incentive, especially in the loss condition. These deleterious effects were statistically eliminated by controlling for mind-wandering, suggesting that loss incentives may paradoxically decrease motivation and focus in older adults.

There are two potential explanations for the poor performance of the older adults in the loss condition. First, when faced with monetary losses related to performance, older adults might have disengaged with the negative situation and reduced their motivation and focus on the task. Alternatively, loss incentives might have amplified the results of making errors, and older adults became anxious and concerned about their own performance. In this case, the increased self-reported mind-wandering might be to performance-related concerns. In other words, concerns about their poor performance may actually have served as a form of distraction, further impairing performance in a "vicious circle".

Chapter III examined different dimensions of motivation and incentive –global context effects, more local run-by-run effects, and a person's motivational tendencies.

In addition to using the same task and between-subjects incentive manipulation in Chapter II, a within-subjects manipulation was added. For the incentivized conditions, experimental runs alternated between incentivized versus non-incentivized conditions. Monetary incentives reduced both young and older adults' attentional performance compared to the situation when incentive was not offered at all. When incentives were offered, performance was worse in runs when incentives were absent. Additional results from self-report measures suggest that for young adults, incentives may be distracting and lead to worse performance. In contrast, older adults were more intrinsically motivated, and the external incentive bonus appeared to decrease their motivation. These results may raise more questions than they answer. However, they highlight potential factors that may not receive sufficient attention in the current literature about the incentive effects on attention and cognitive control, or about age-related differences in that regard. Most importantly, they indicate that the effects of incentive may be influenced by the incentive structure. In this experiment, although incentives have beneficial effects on performance <u>*within*</u> subjects, they may have quite different, and perhaps even detrimental, effects <u>*between*</u> subjects.

Together, these two experiments demonstrate the complex, multi-dimensional nature of attention-motivation interactions. Contrary to the general assumptions that monetary incentives increase motivation and improve performance, the effects of incentive are sometimes-paradoxical, and are influenced by a variety of factors such as an individual's age (young or older adults) and the type of incentive scheme (between and within subject manipulation).

Selection is the very keel on which our mental ship is built. And in this case of memory its utility is obvious. If we remembered everything, we should on most occasions be as ill off as if we remembered nothing. — William James

This quote from James illustrates that the limits on our attention also lead to limits on your memory, and that we must make decisions – consciously or not – as to what we will learn and remember. Finally, Chapter IV investigates outcome probability and valence influence learning as well as subsequent explicit memory. It seems intuitive that the value of information should influence which aspects are learned and remembered, but again the data reported here suggest that the situation is more nuanced than it may at first appear. The effects of positive or negative (wins or losses) incentive value are not merely "mirror images" of each other, and the salience (probability) of an outcome may have different effects in win and loss conditions. Results revealed superior learning of win associations compared to loss associations, suggesting an advantage for outcomes with a positive valence. Regardless of learning level or incentive condition, source recognition was superior for scenes that had been chosen most frequently (high probability win and low probability loss) but more accurately for win than loss scenes. These findings indicate that learning to select the optimal choice is dissociable from explicit knowledge about the outcome contingencies, especially for loss and low probability outcomes. Moreover, motivational salience is represented differentially in explicit memory for win and loss outcomes.

Of course, the three experiments reported here cannot fully elucidate the complexities of incentive and motivation effects on attention, learning, and memory, and in many cases raise more questions than they answer. However, taken together, they demonstrate the complex effects of incentive structure, individual differences, and outcomes associated with stimuli. In some cases, the results contradicted our initial hypotheses, to which one might apply a final William James quote, "*Those thoughts are truth which guide us to beneficial interaction with sensible particulars as they occur, whether they copy these in advance or not.*" In short, the findings of this dissertation show that factors often "taken for granted" in many experiments of incentive effects on attention and memory may have more complex effects than currently realized, and that these may impact the degree to which the results of those experiments translate to everyday life. We do indeed hope that these questions will motivate further research, and that the results will have value for improving the real-world performance and well-being of both younger and older adults.